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Philippou et al.

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(54) **IGBT WITH DV/DT CONTROLLABILITY**

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(51) **Int. Cl.**
H01L 29/73 (2006.01)
H01L 29/739 (2006.01)
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(Continued)

(58) **Field of Classification Search**
CPC combination set(s) only.
See application file for complete search history.

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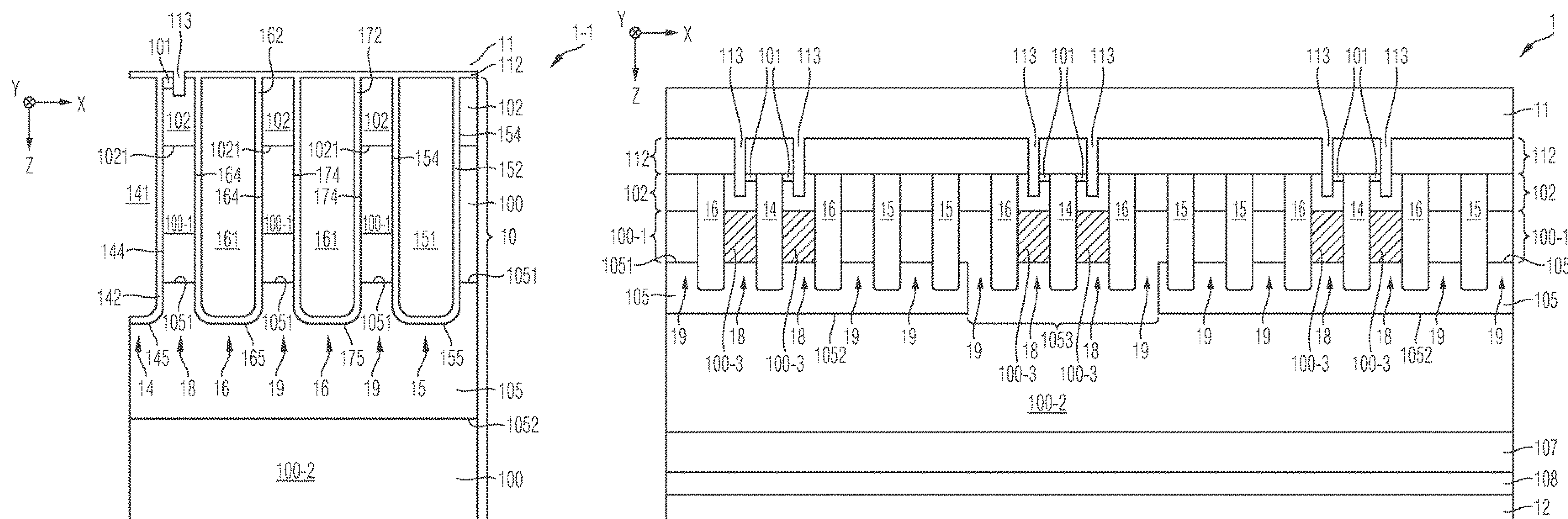
(74) *Attorney, Agent, or Firm* — Murphy, Bilak & Homiller, PLLC

(57) **ABSTRACT**

A power semiconductor device includes an active cell region with a drift region of a first conductivity type, a plurality of IGBT cells arranged within the active cell region, each of the IGBT cells includes at least one trench that extends into the drift, an edge termination region surrounding the active cell region, a transition region arranged between the active cell region and the edge termination region, at least some of the IGBT cells are arranged within or extend into the transition region, a barrier region of a second conductivity type, the barrier region is arranged within the active cell region and in contact with at least some of the trenches of the IGBT cells and does not extend into the transition region, and a first load terminal and a second load terminal, the power semiconductor device is configured to conduct a load current along a vertical direction between.

19 Claims, 26 Drawing Sheets



(51) **Int. Cl.**

H01L 29/06	(2006.01)
H01L 29/40	(2006.01)
H01L 29/66	(2006.01)
H01L 29/08	(2006.01)
H01L 29/10	(2006.01)
H01L 29/417	(2006.01)
H01L 29/423	(2006.01)

(52) **U.S. Cl.**

CPC ***H01L 29/0623*** (2013.01); ***H01L 29/0638*** (2013.01); ***H01L 29/0649*** (2013.01); ***H01L 29/0696*** (2013.01); ***H01L 29/0804*** (2013.01); ***H01L 29/1095*** (2013.01); ***H01L 29/407*** (2013.01); ***H01L 29/41708*** (2013.01); ***H01L 29/66348*** (2013.01); ***H01L 29/7396*** (2013.01); *H01L 29/4238* (2013.01)

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FIG 1

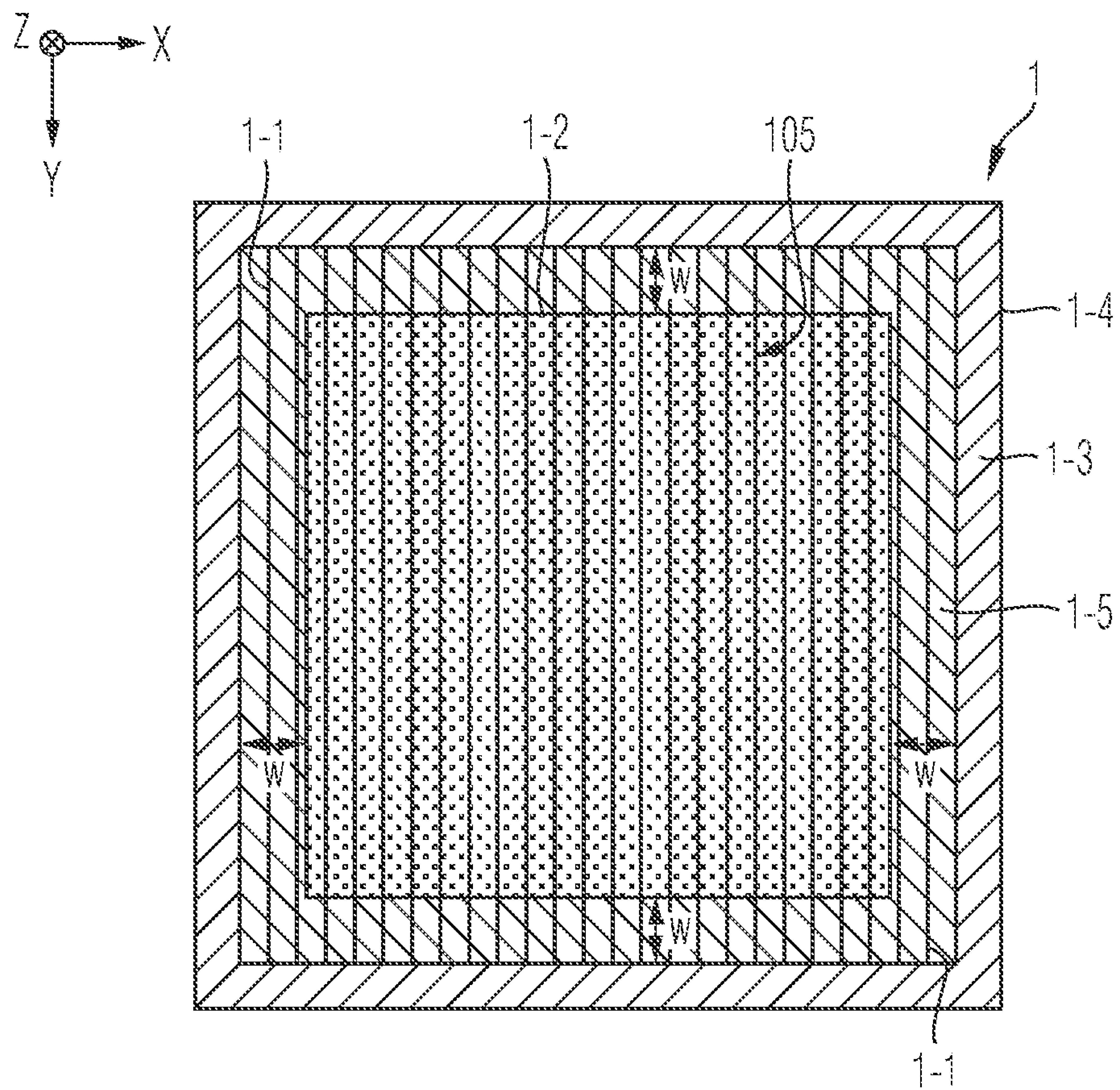
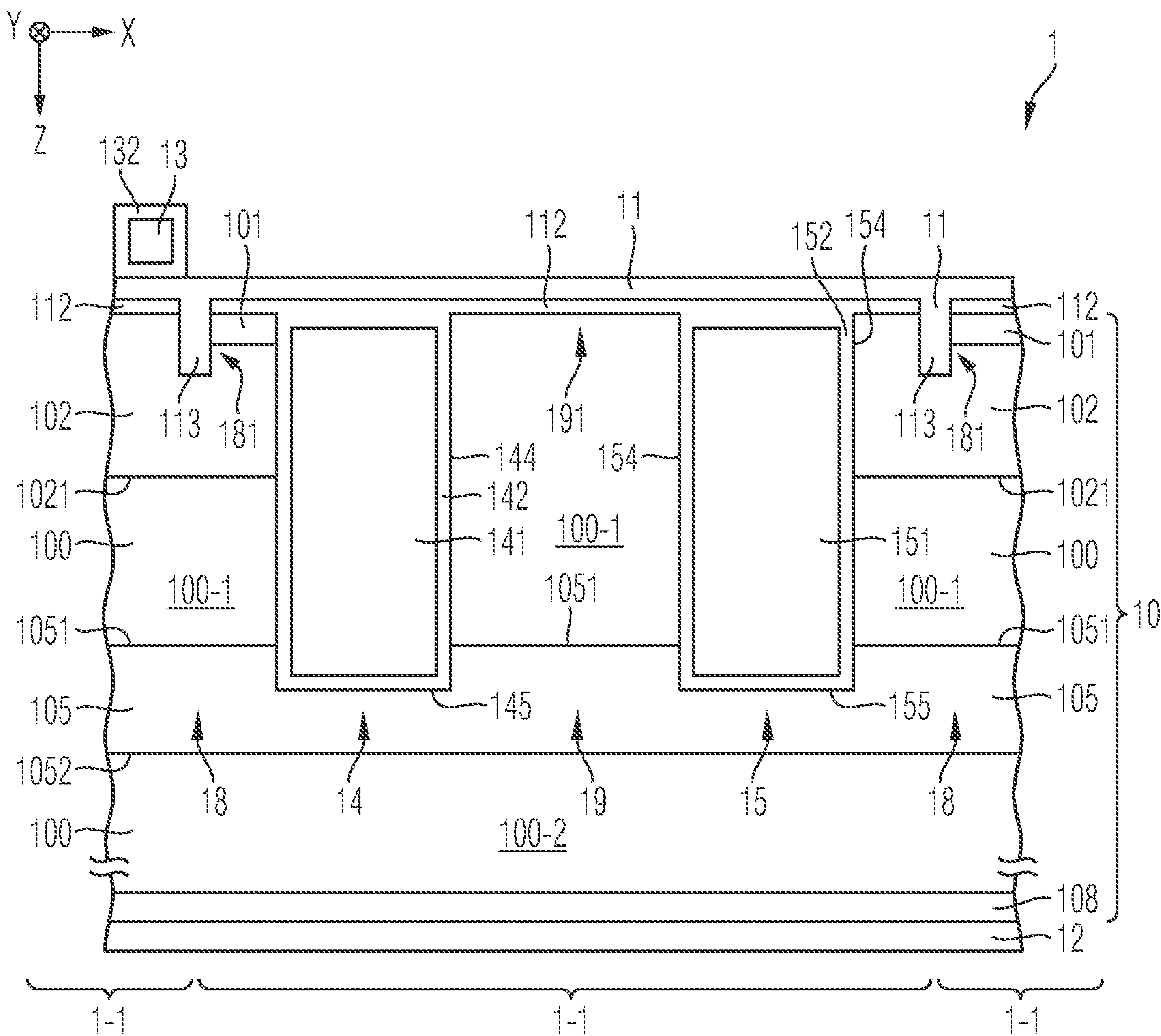
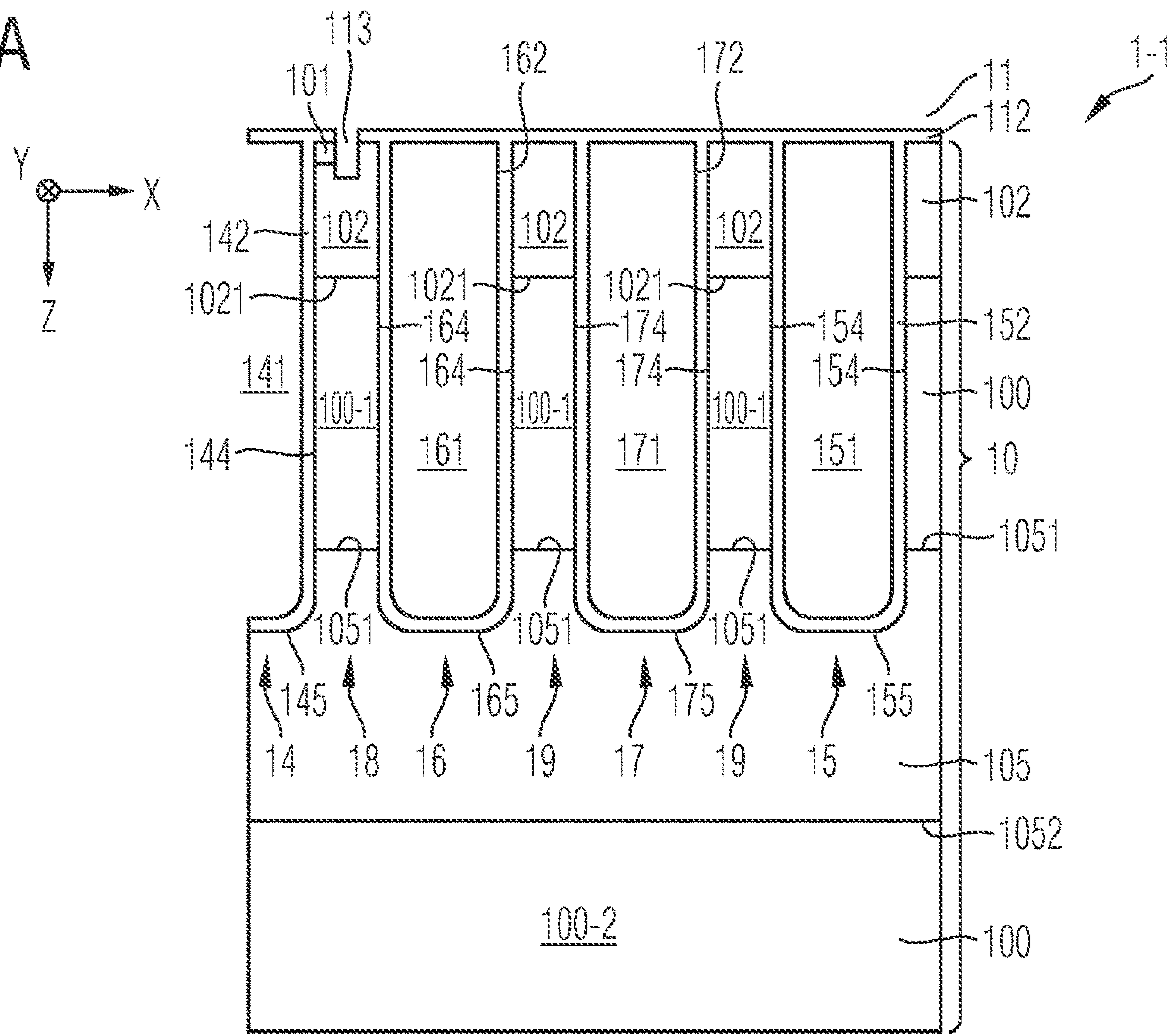


FIG 2

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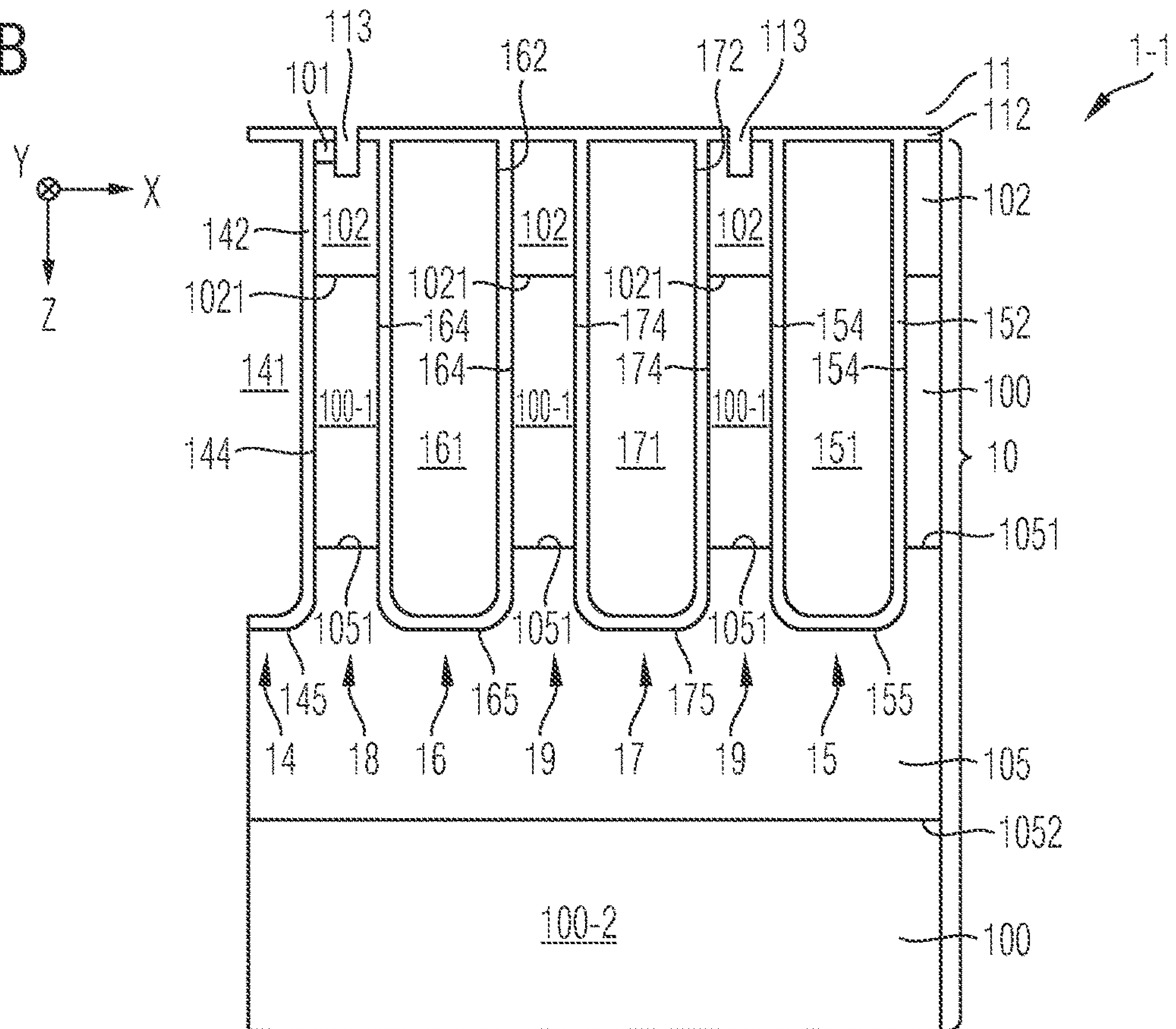
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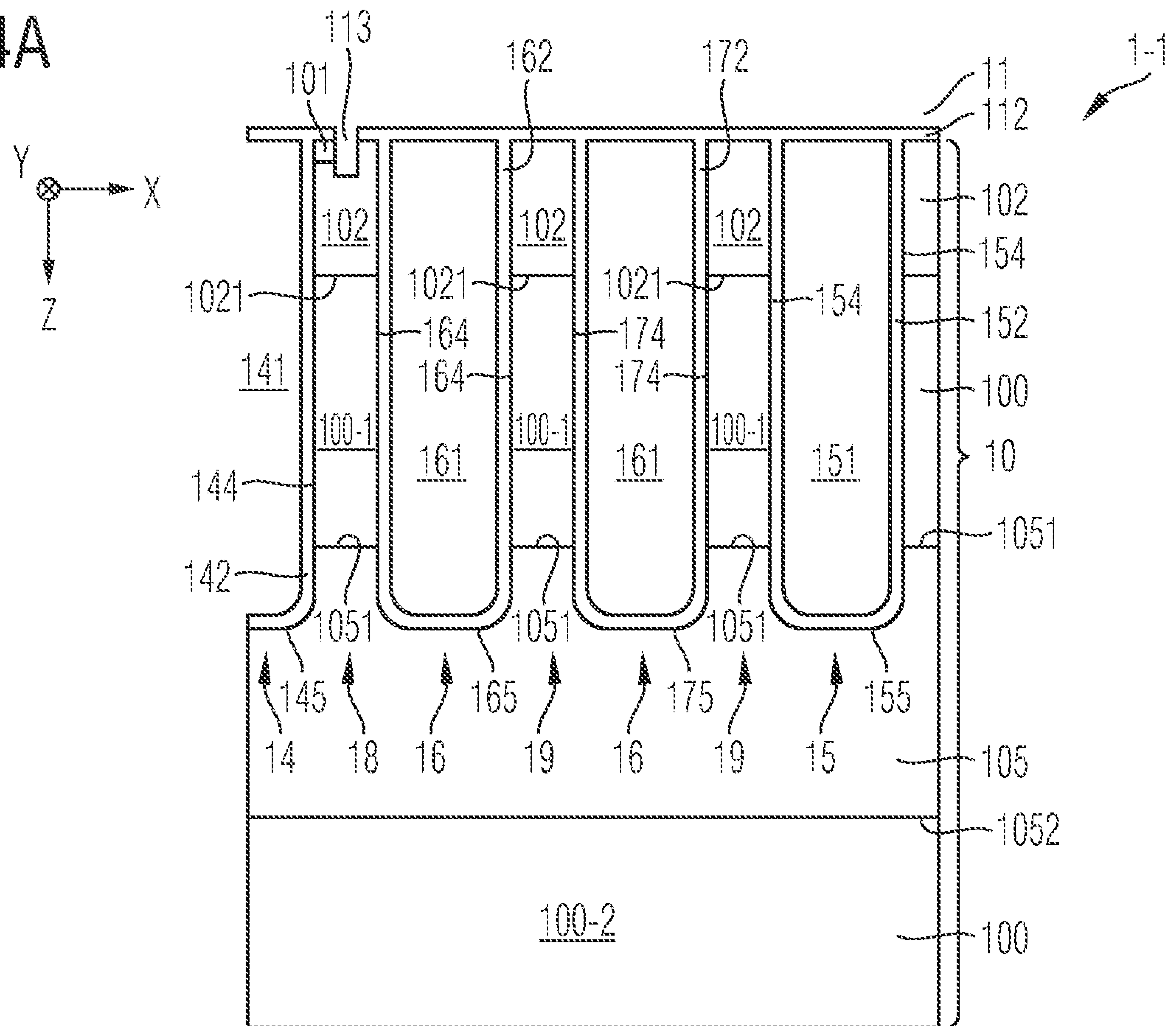
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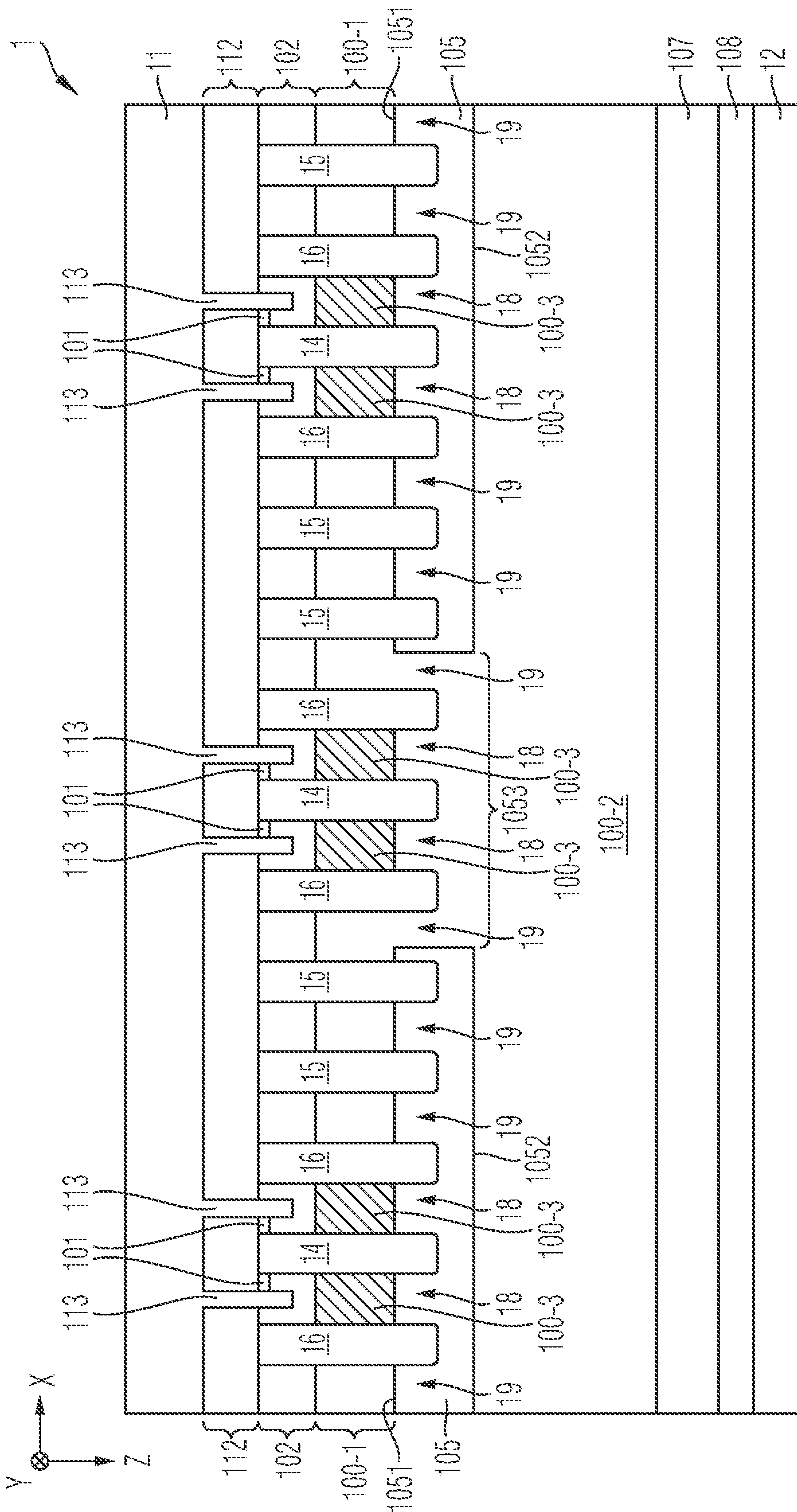
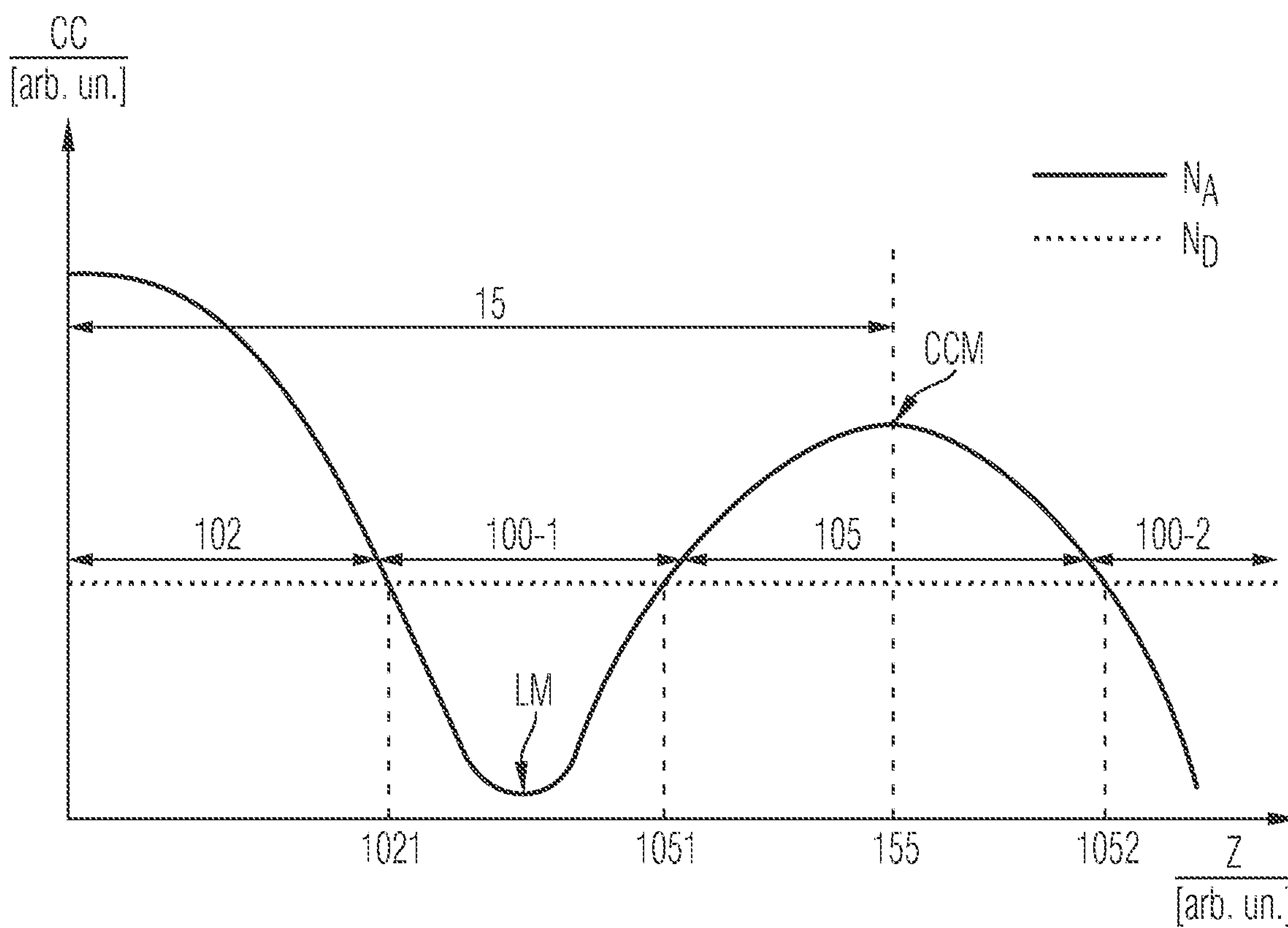


FIG 4B

FIG 5



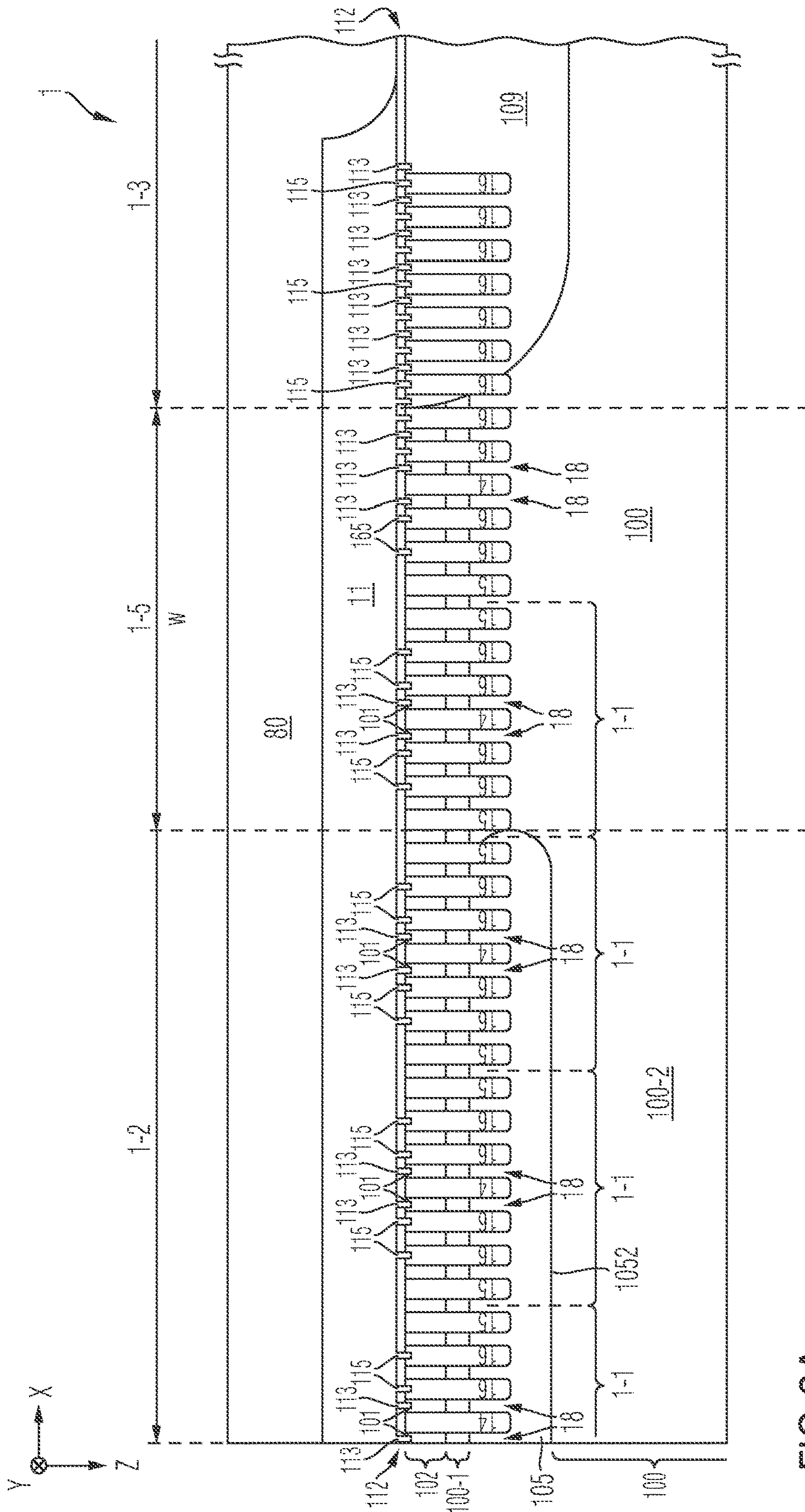


FIG 6A

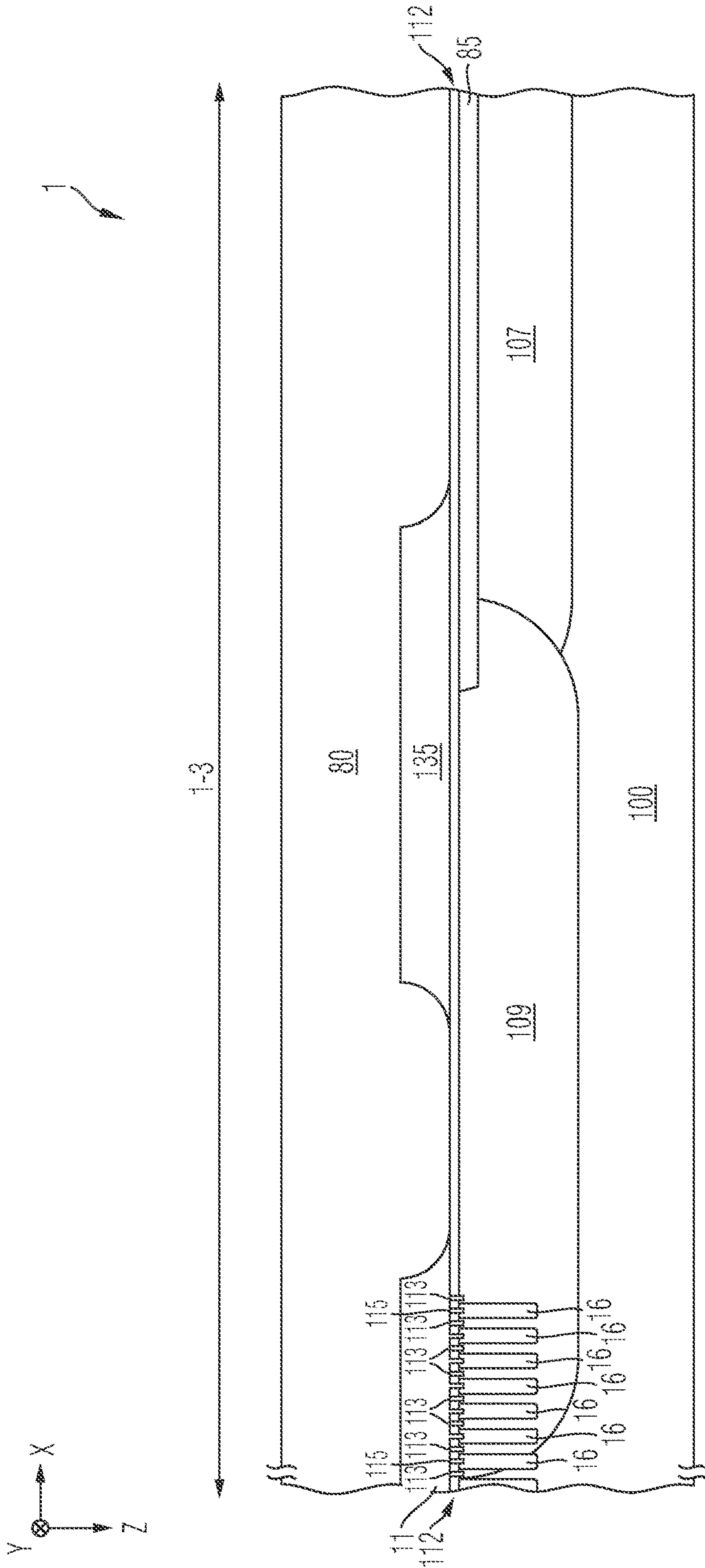


FIG 6B

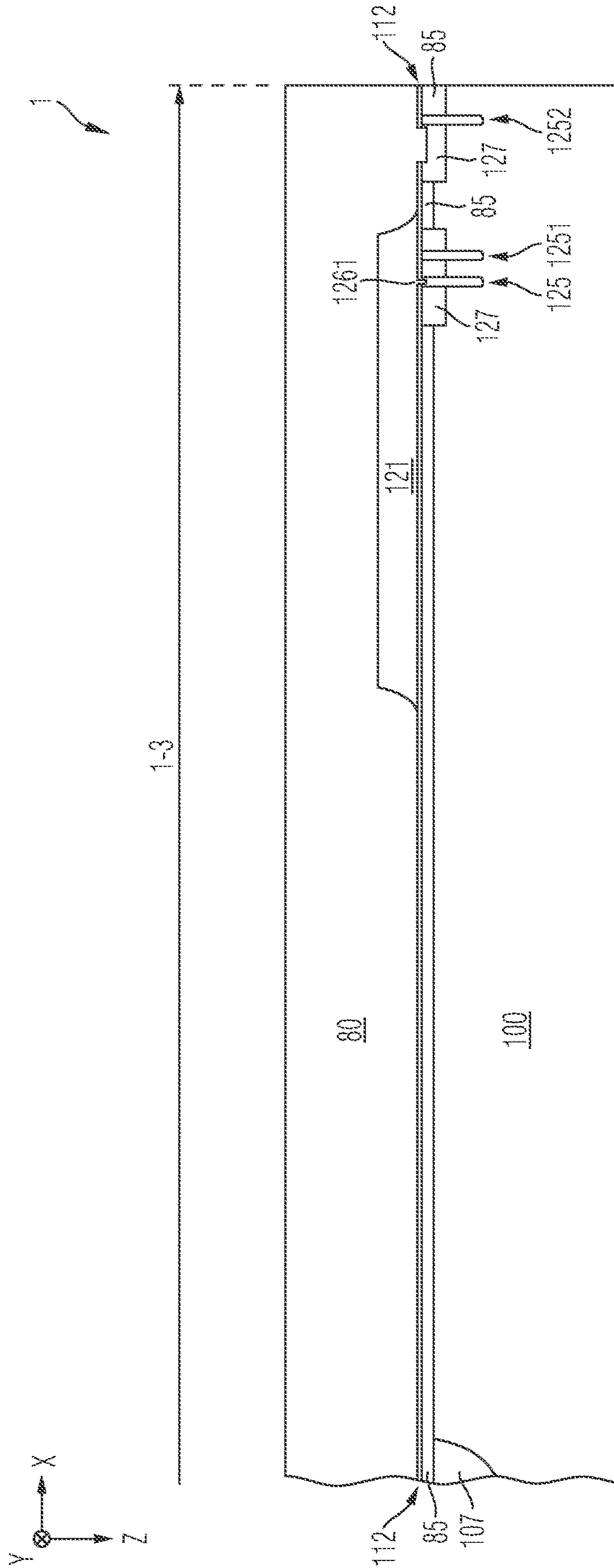
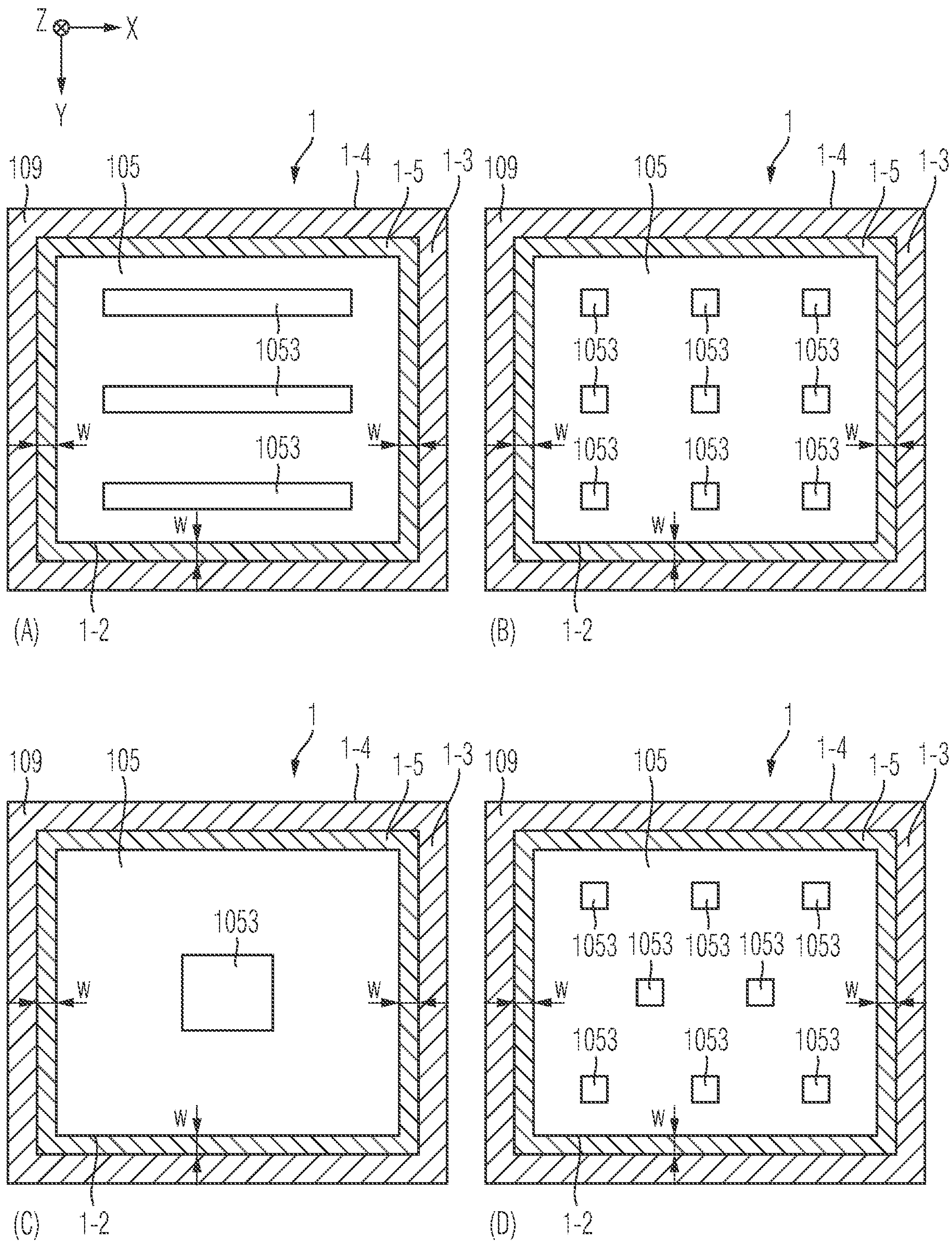


FIG 6C

FIG 7



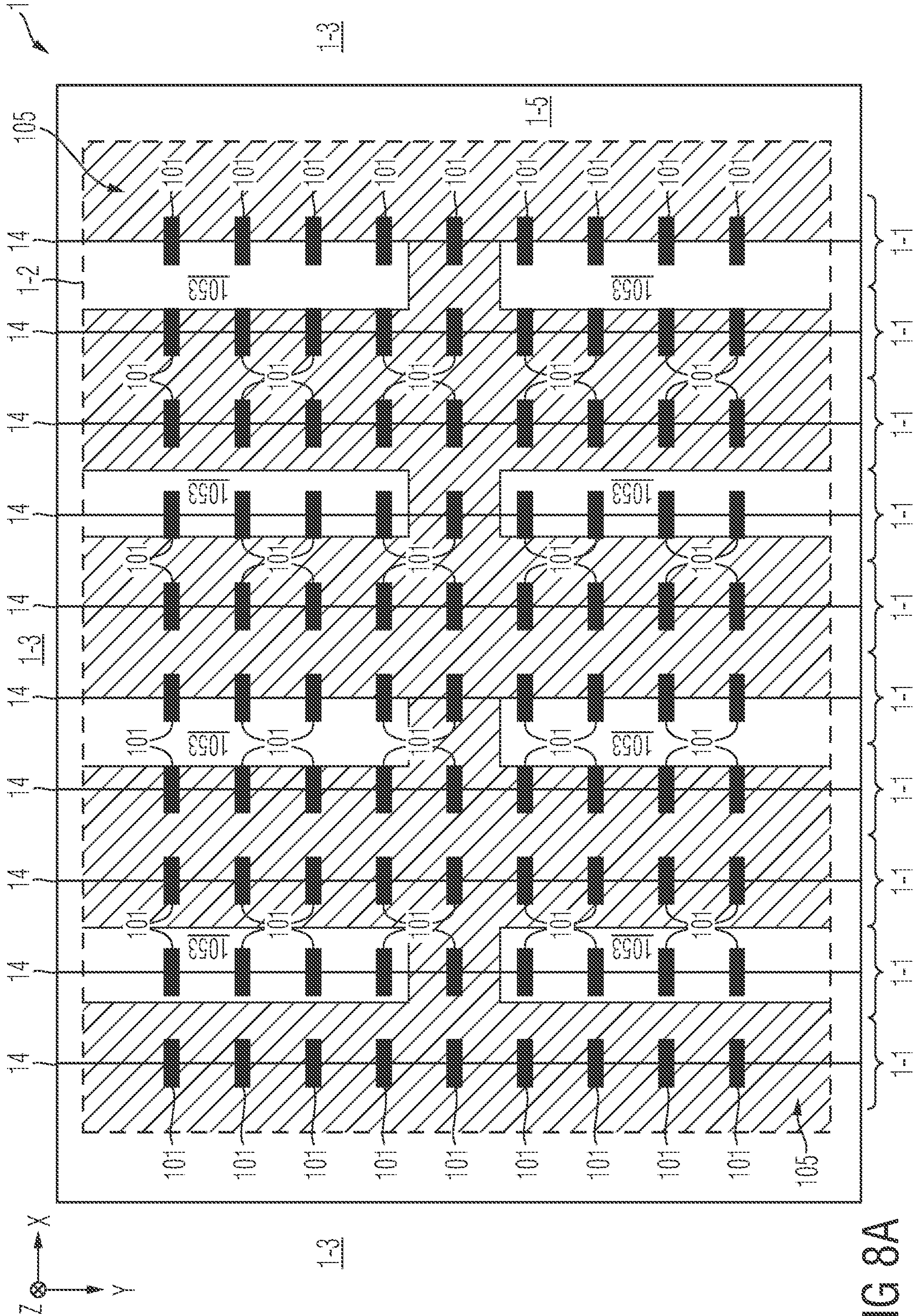


FIG 8A

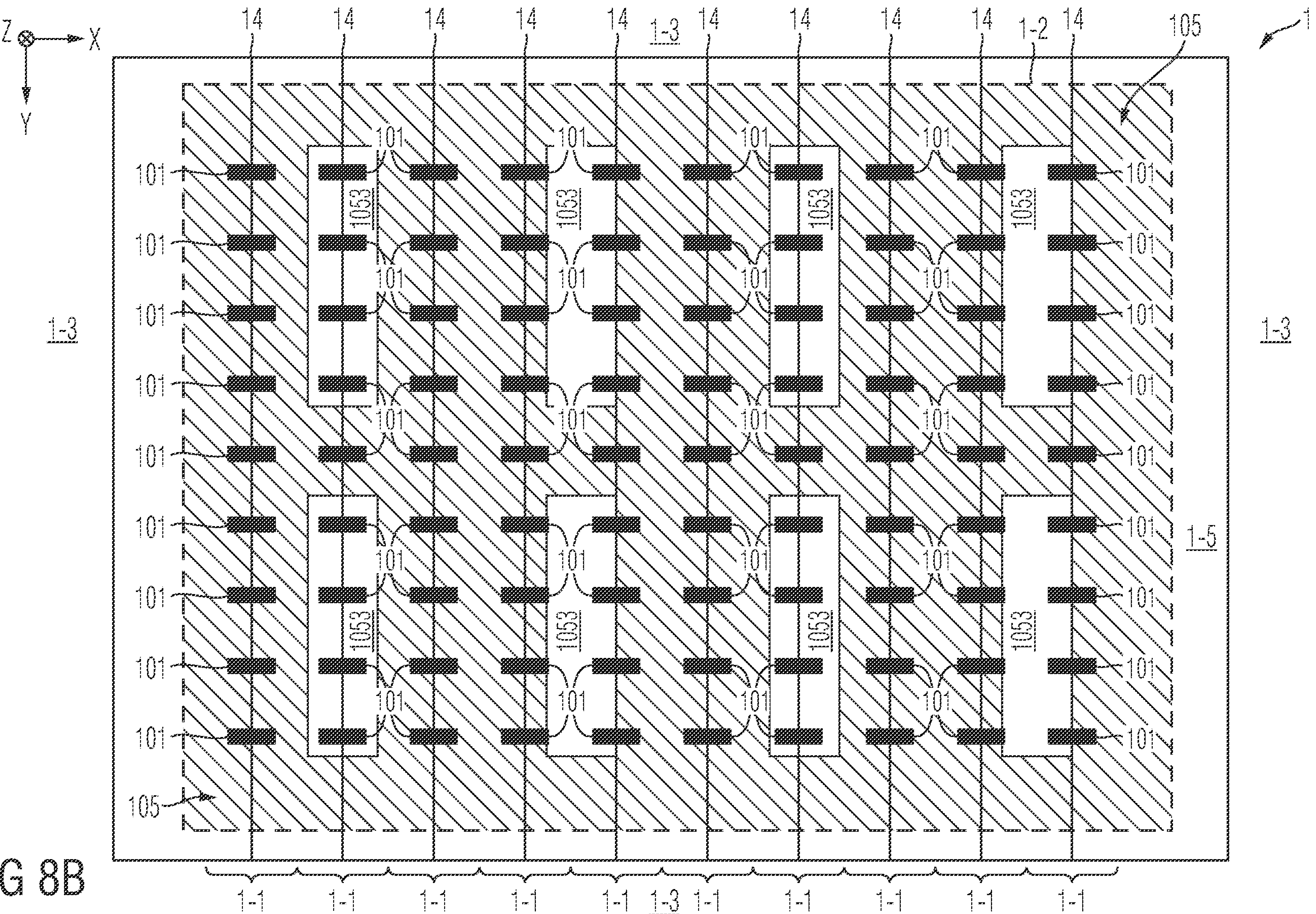
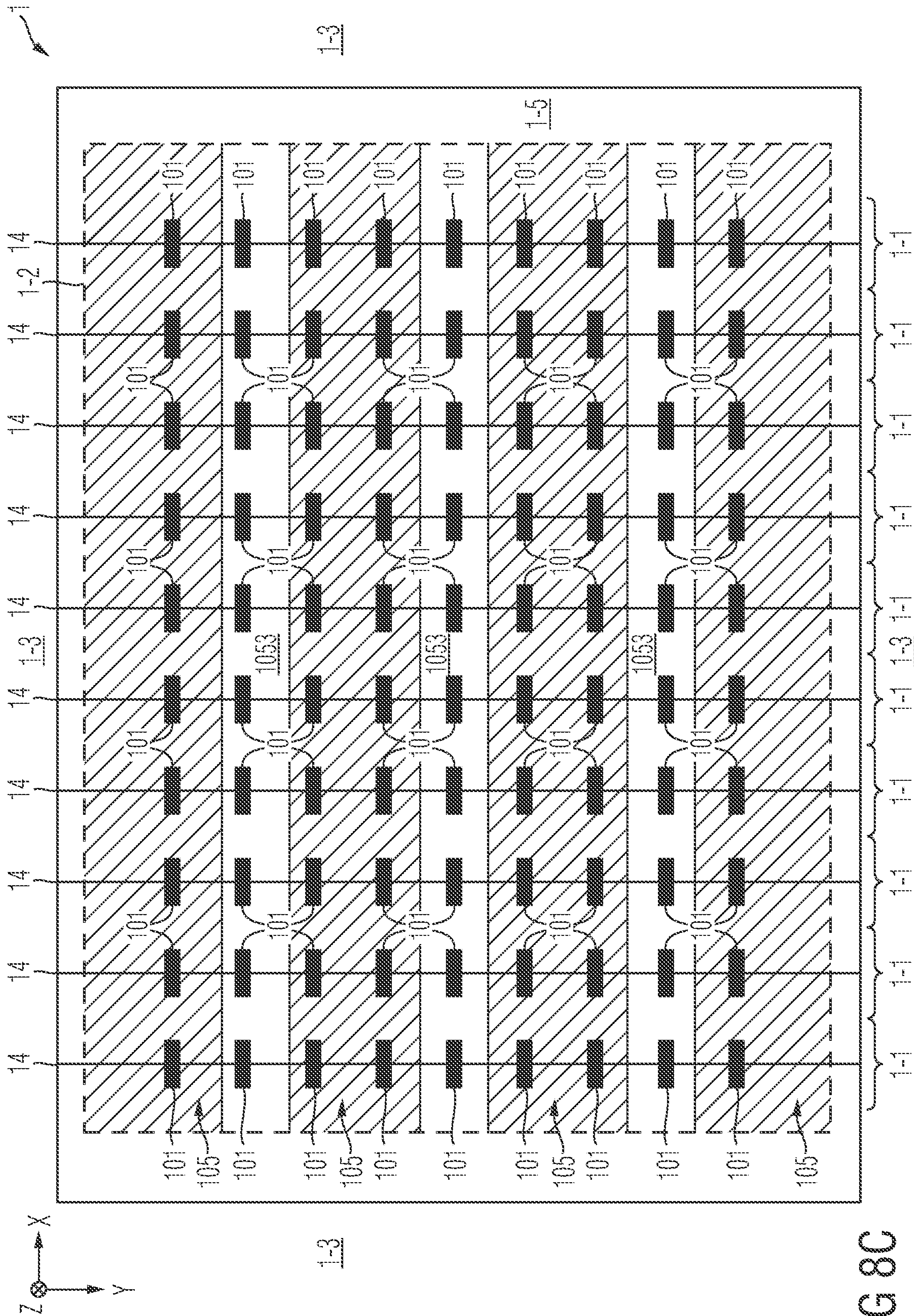


FIG 8B



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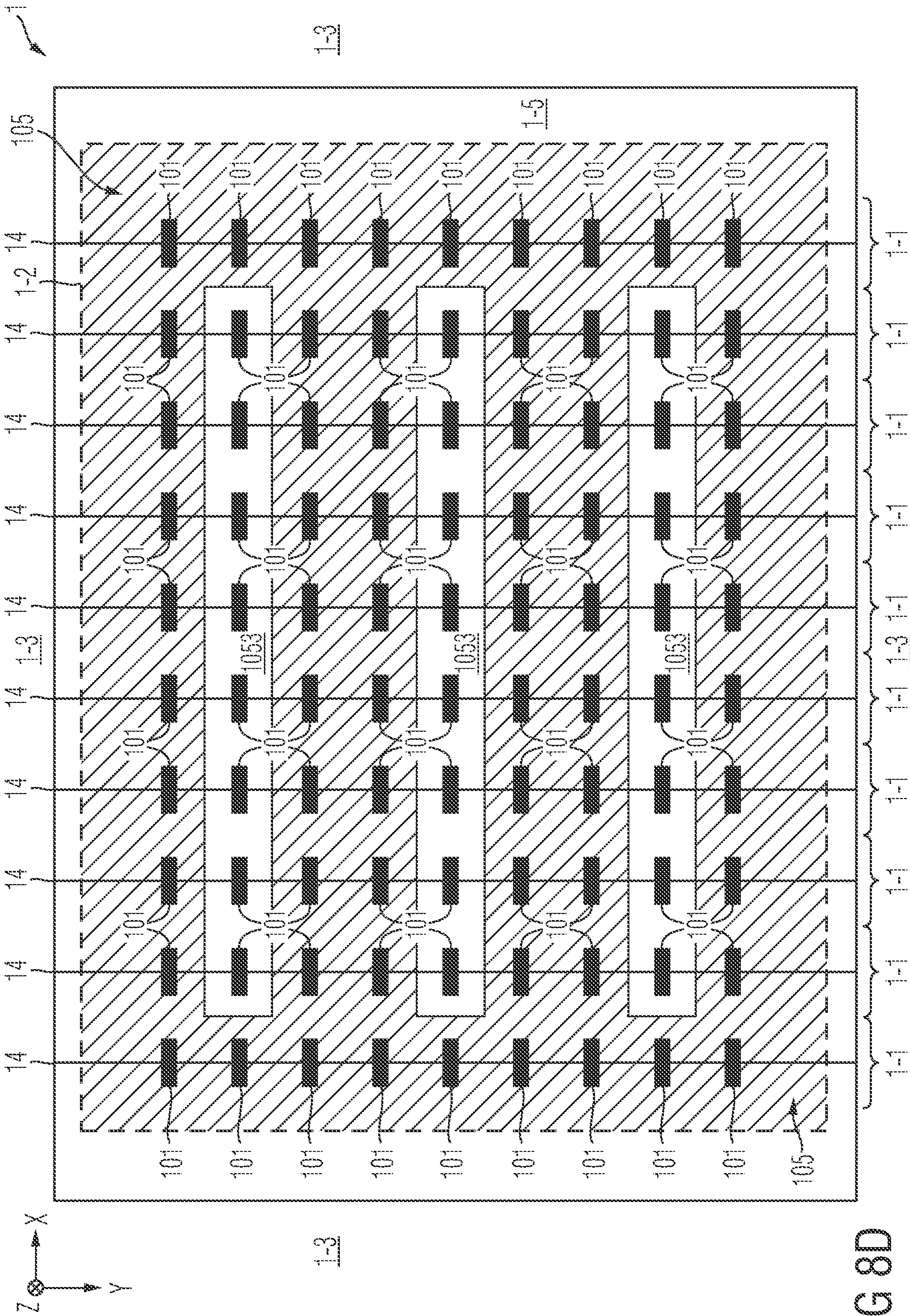

FIG 8D

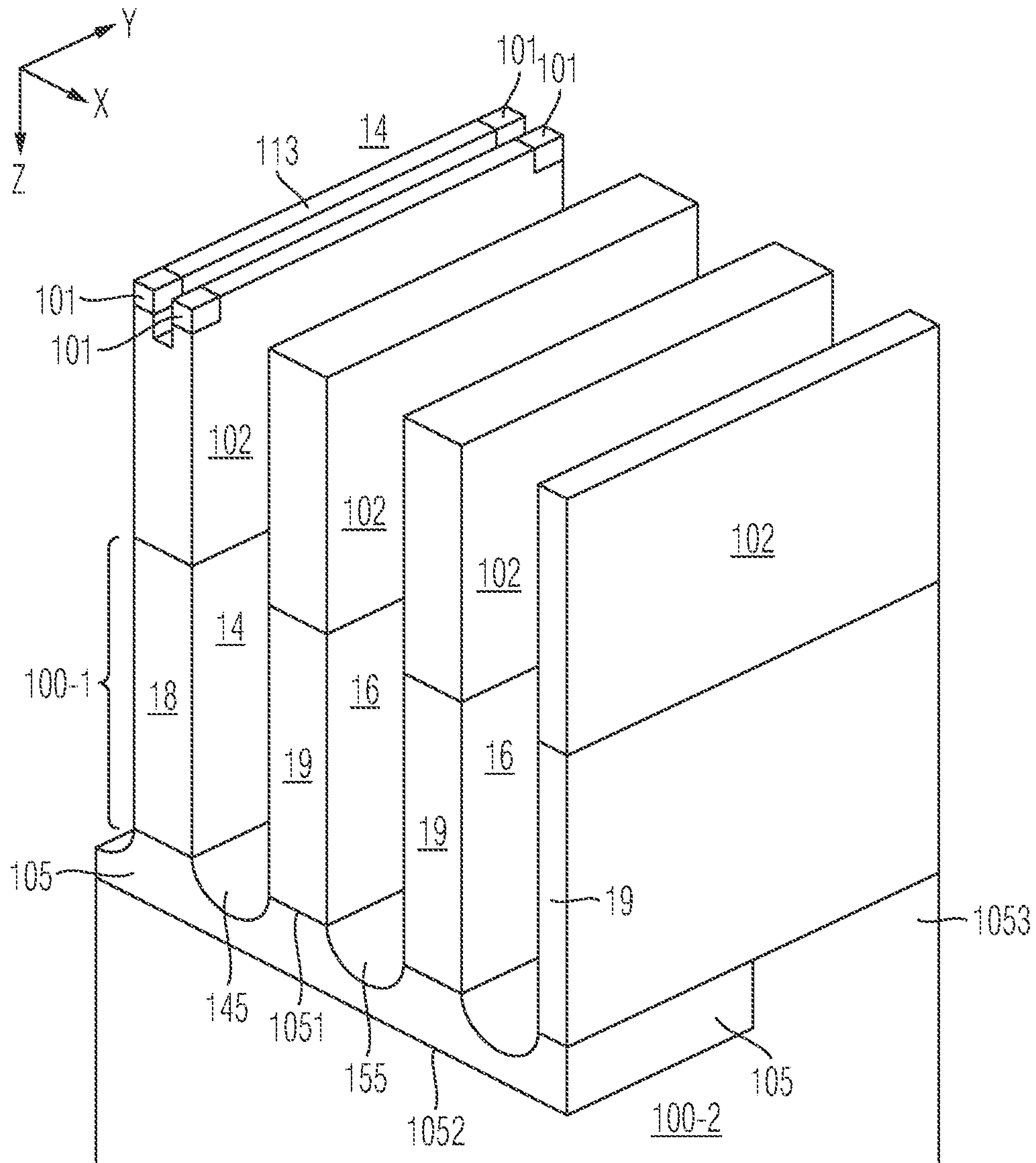

FIG 9

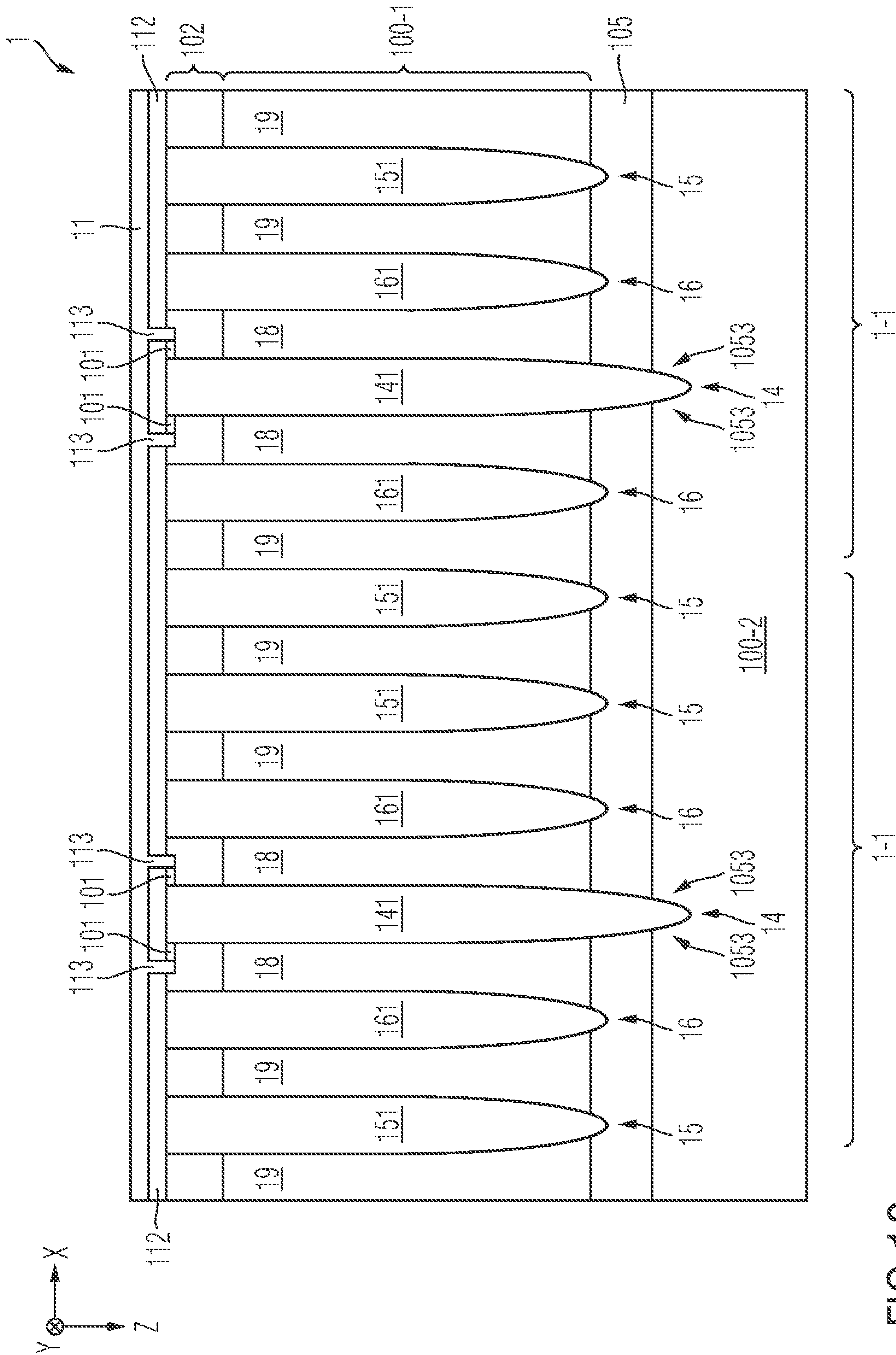

FIG 10

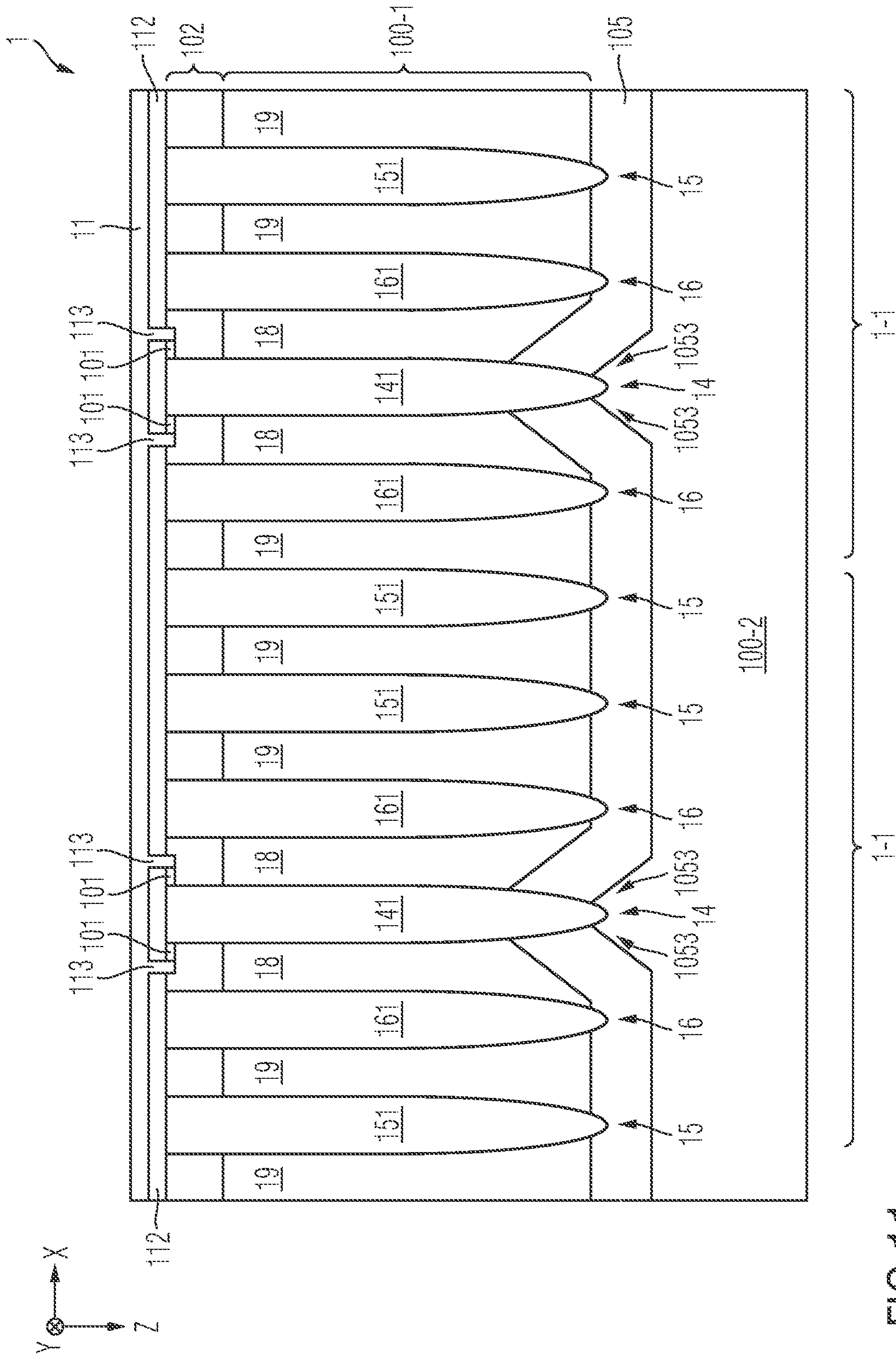
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FIG 11

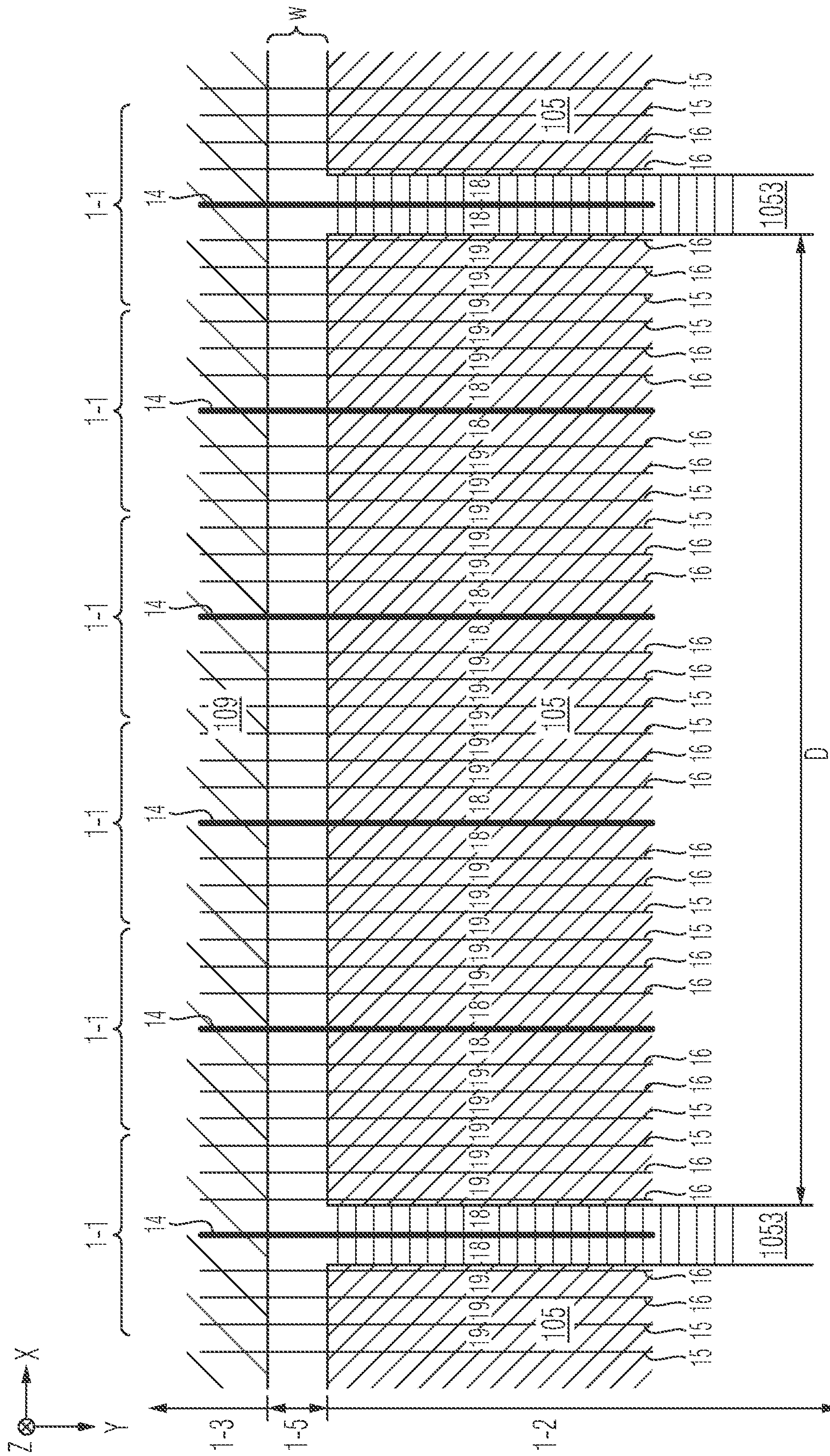

FIG 12

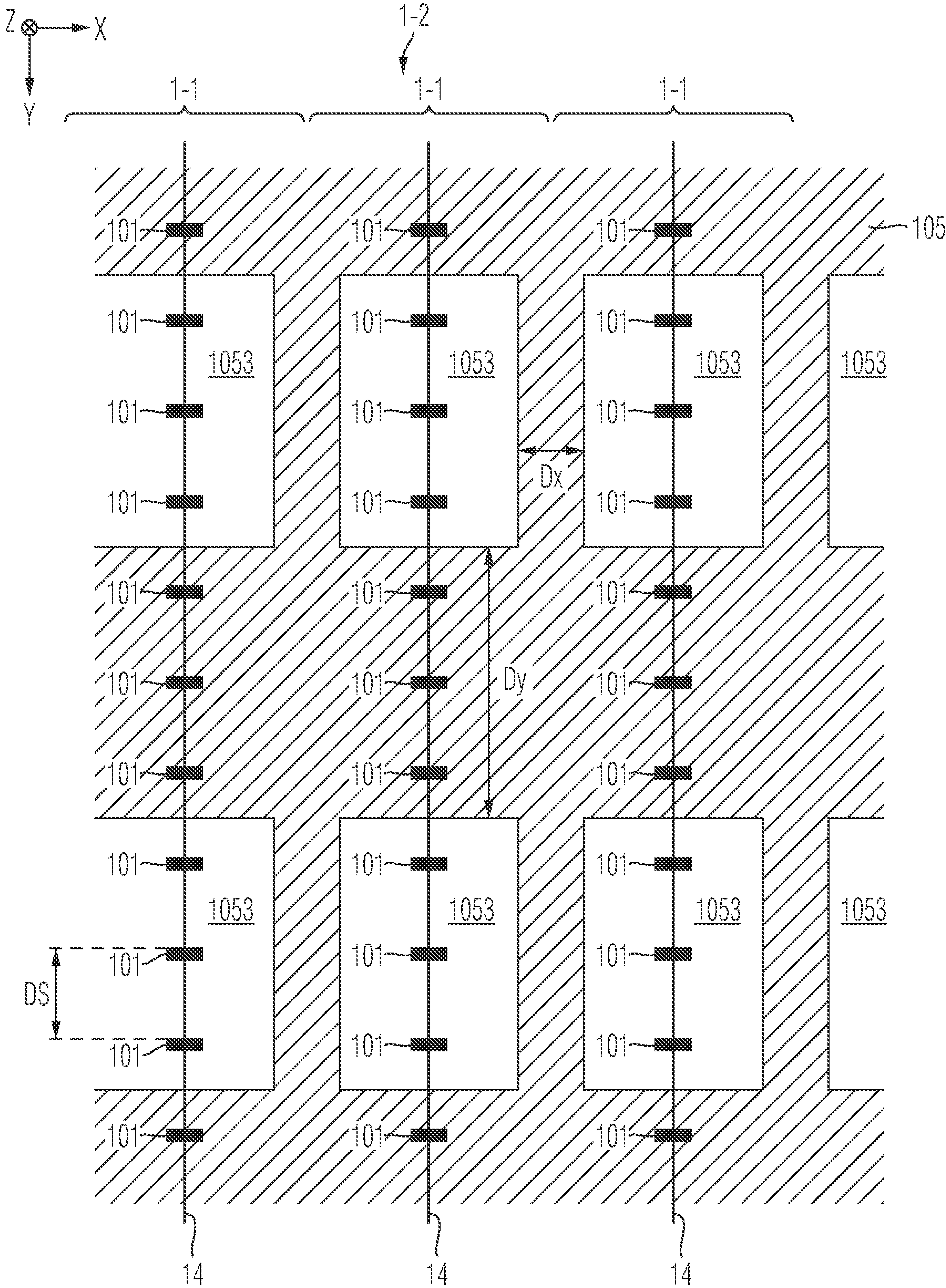

FIG 13

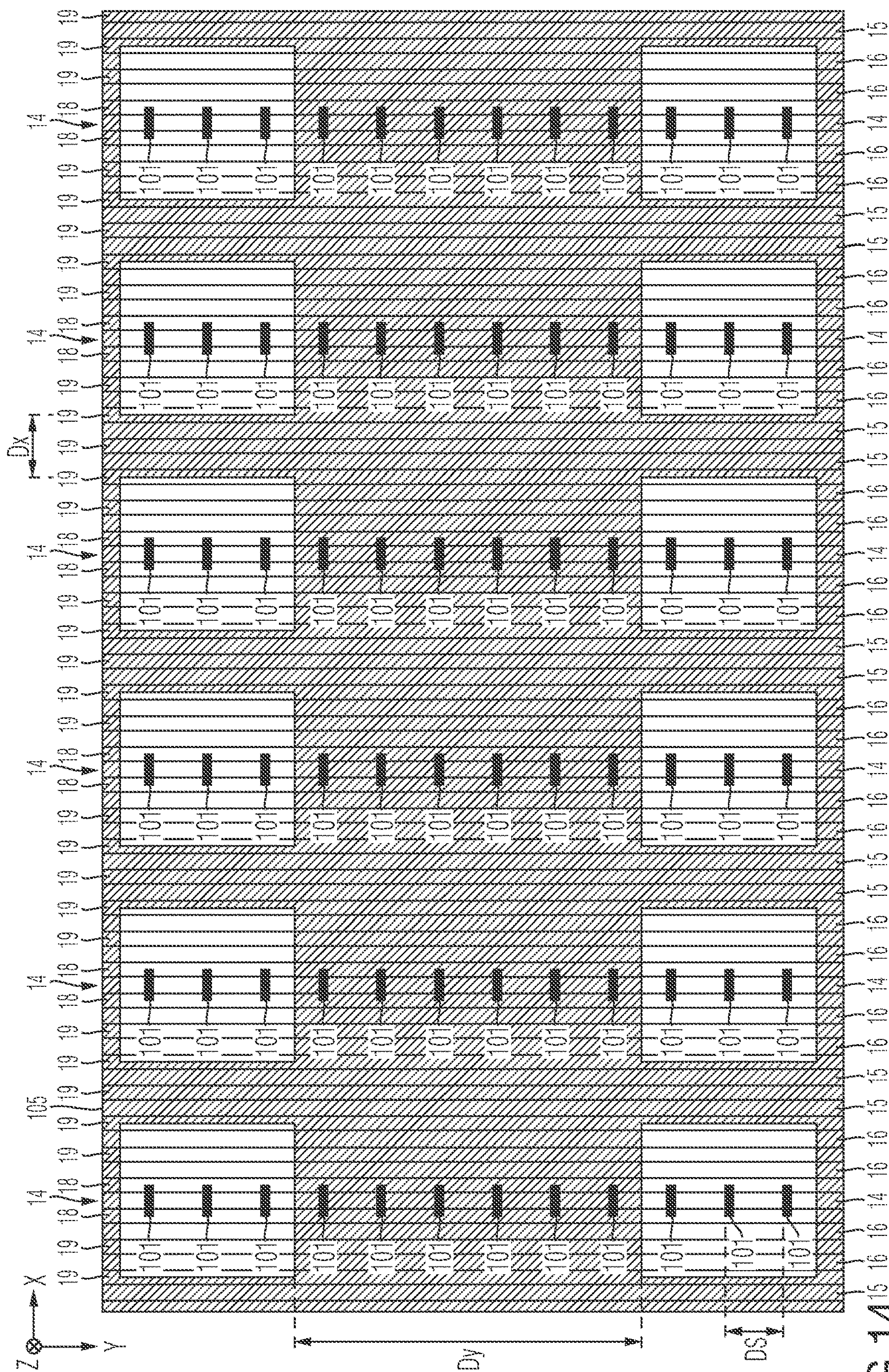

FIG 14

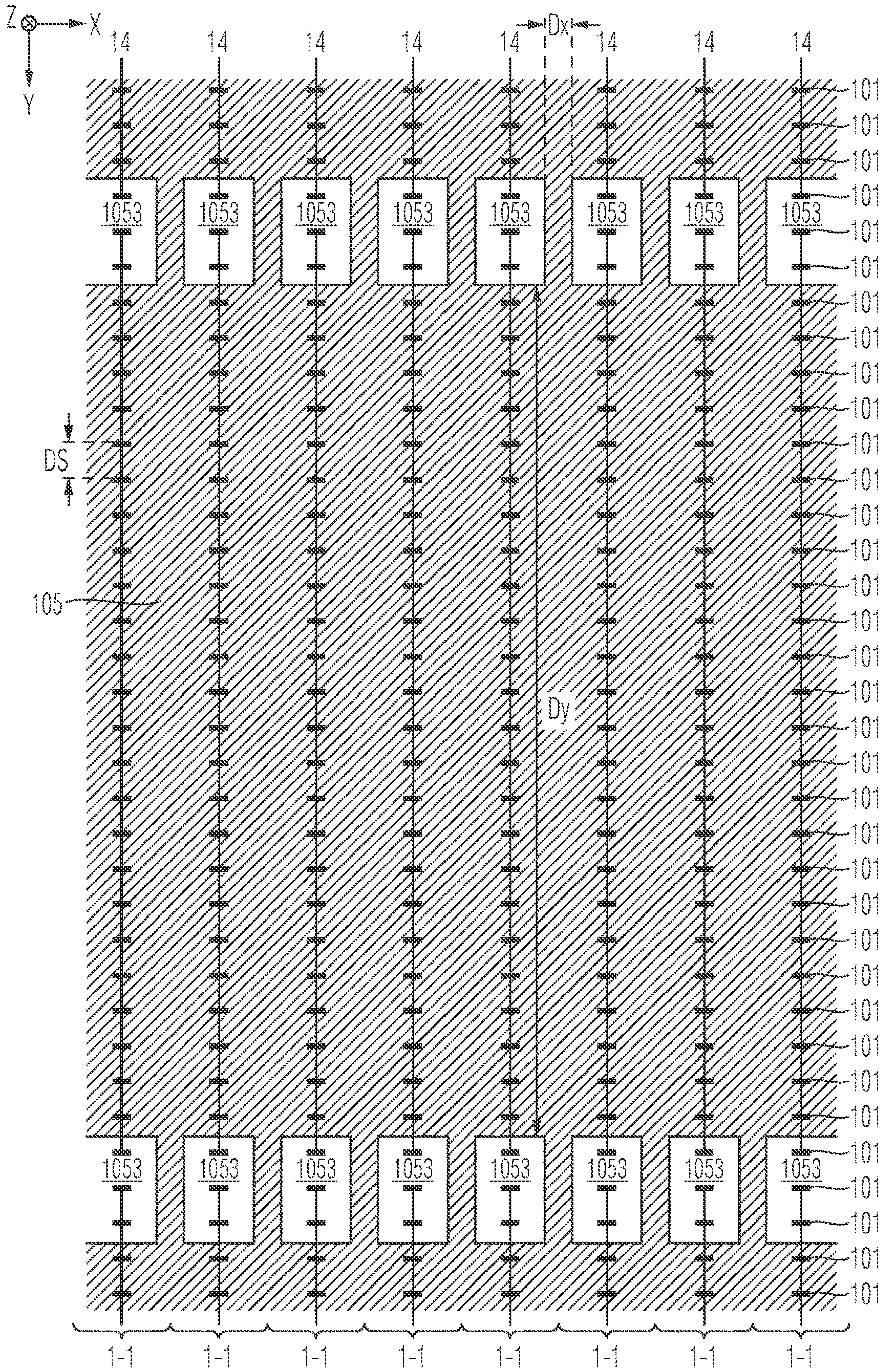

FIG 15

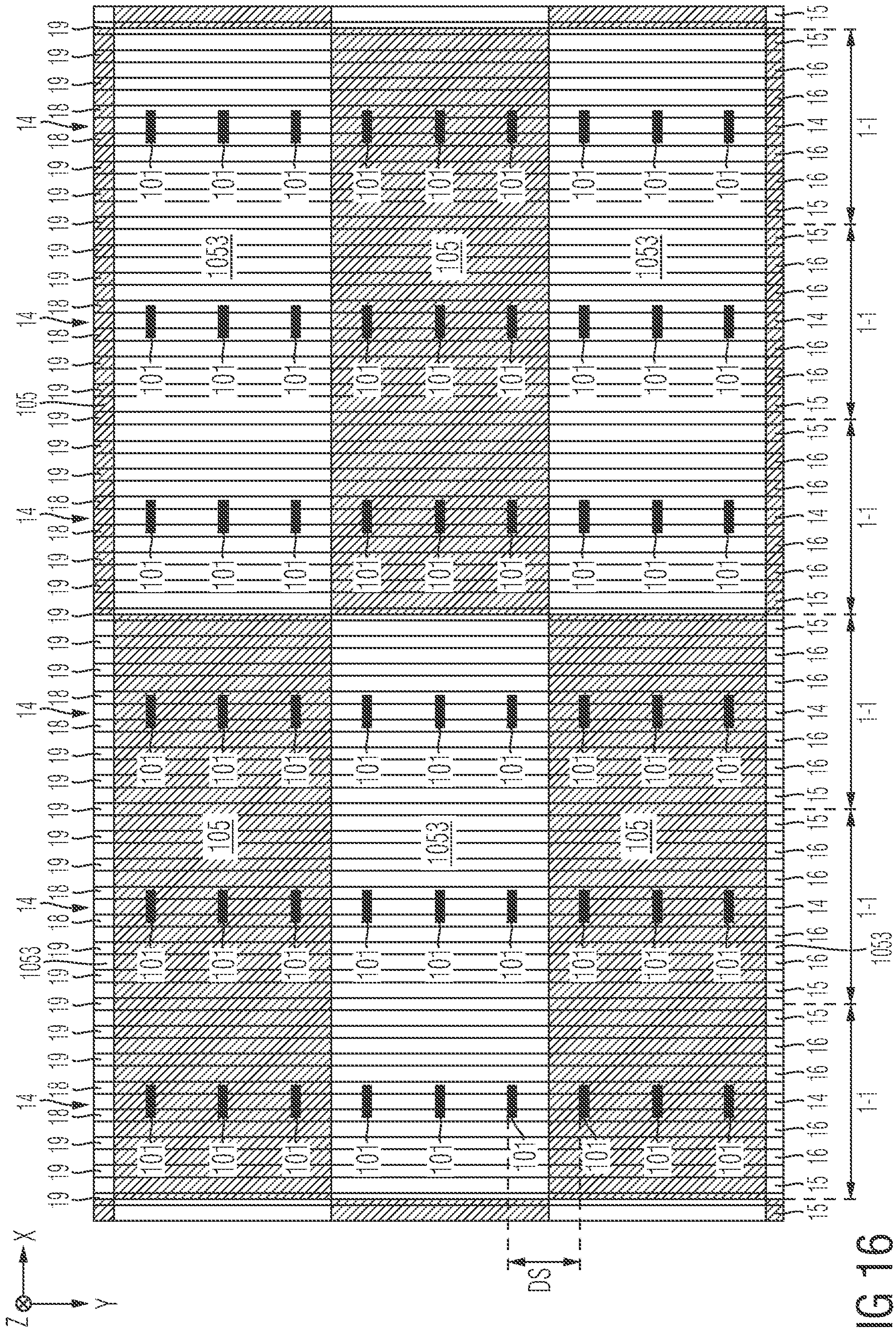
FIG 16
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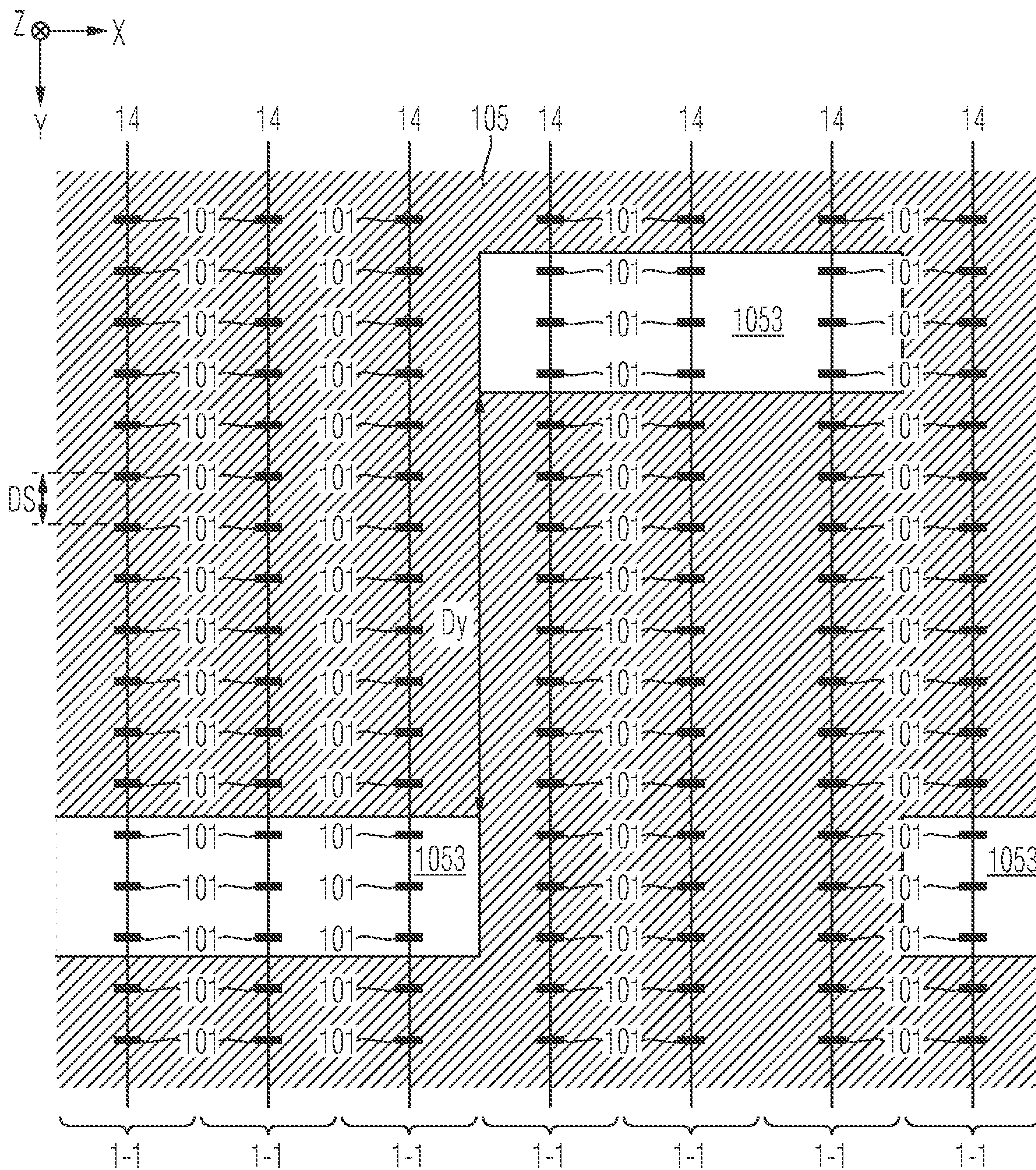

FIG 17

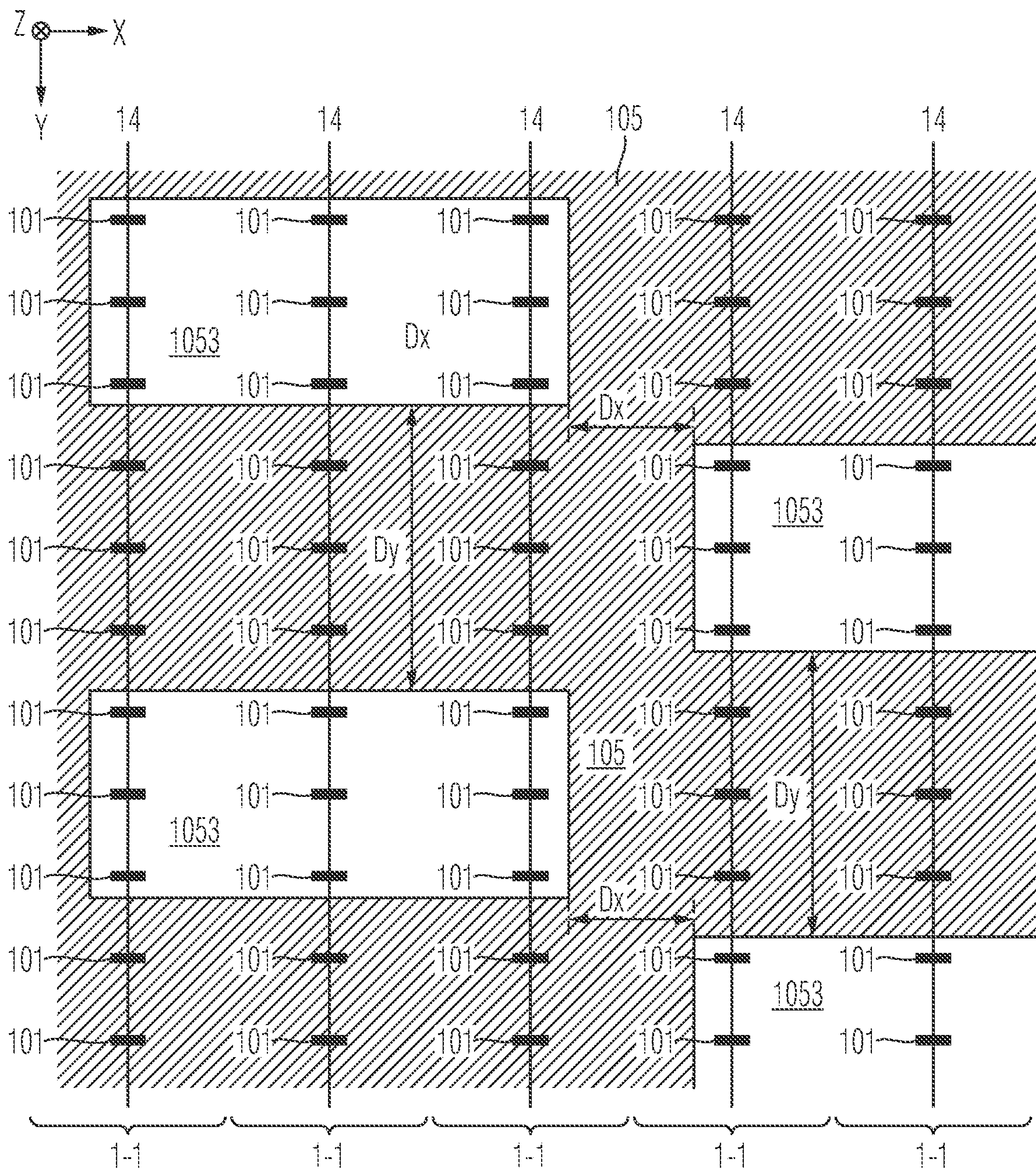

FIG 18

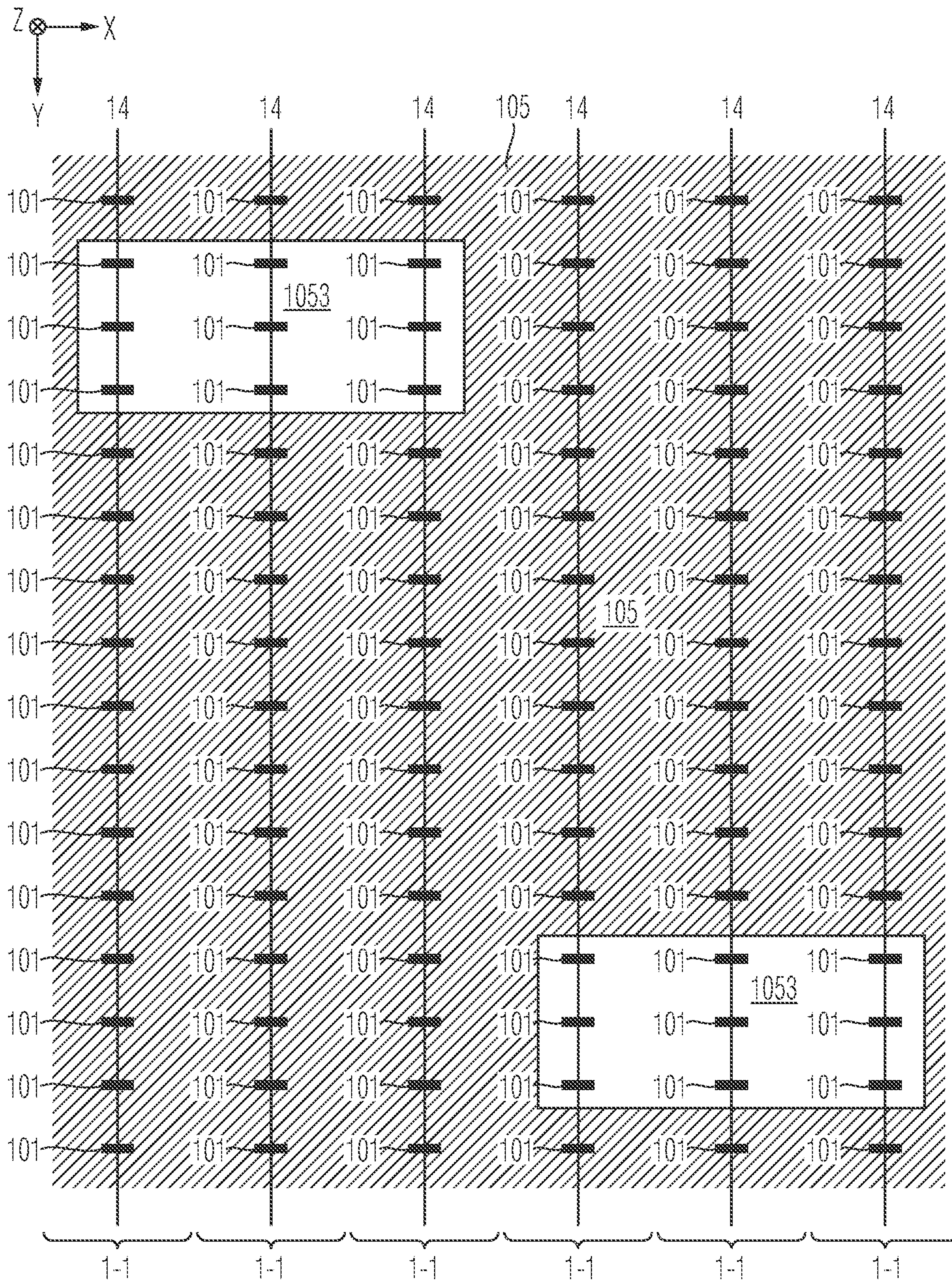

FIG 19

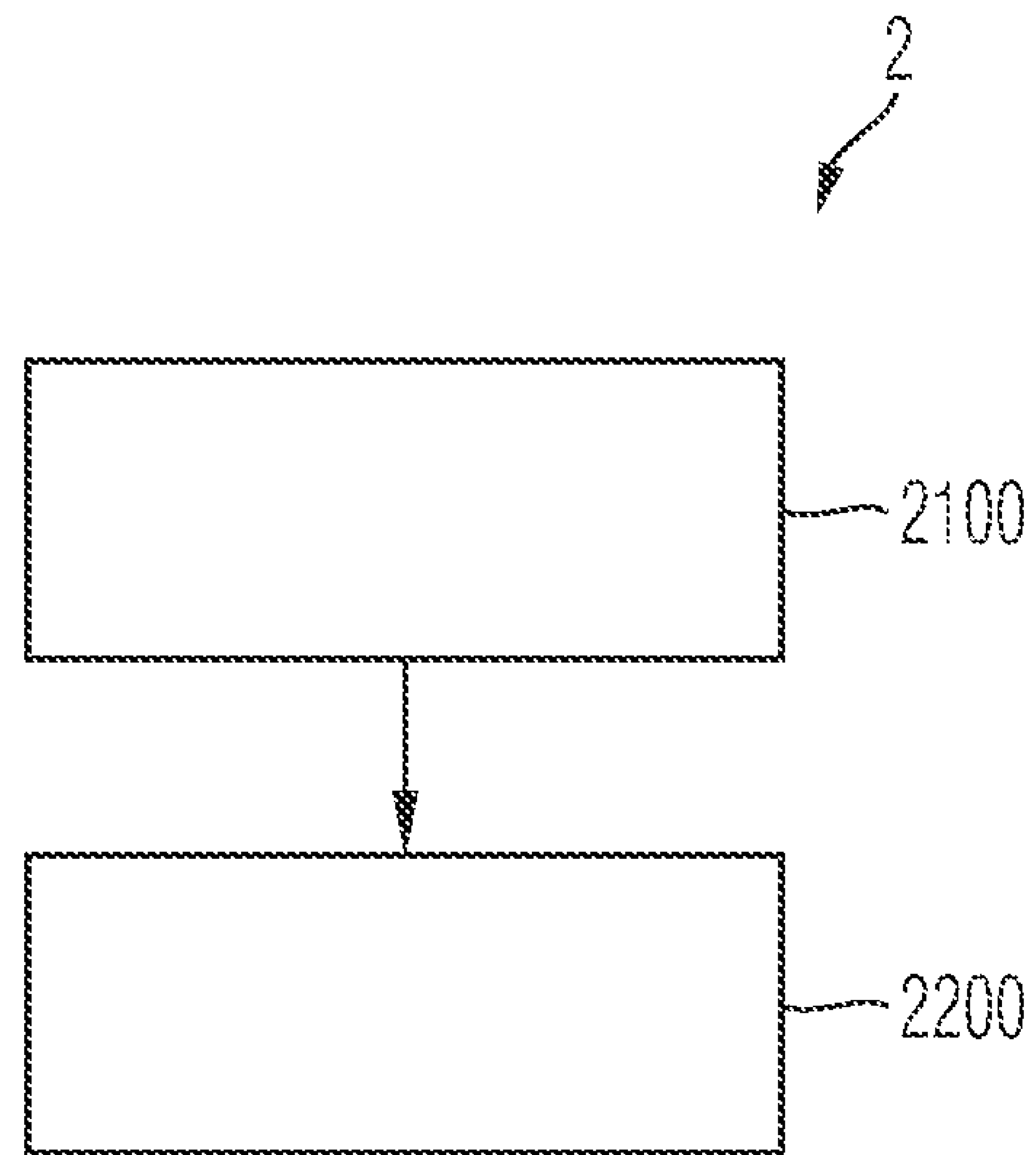

FIG 20

IGBT WITH DV/DT CONTROLLABILITY

TECHNICAL FIELD

This specification refers to embodiments of a power semiconductor device, such as an IGBT, and to embodiments of processing a power semiconductor device. In particular, this specifications refers to embodiments of an IGBT that has a Micro-Pattern-Trench (MPT) configuration, including dummy trenches, wherein a plurality of trenches extend into an electrically floating barrier region.

BACKGROUND

Many functions of modern devices in automotive, consumer and industrial applications, such as converting electrical energy and driving an electric motor or an electric machine, rely on power semiconductor devices. For example, Insulated Gate Bipolar Transistors (IGBTs), Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and diodes, to name a few, have been used for various applications including, but not limited to switches in power supplies and power converters.

An IGBT usually comprises a semiconductor body configured to conduct a load current along a load current path between two load terminals of the IGBT. Further, the load current path may be controlled by means of an insulated electrode, sometimes referred to as gate electrode. For example, upon receiving a corresponding control signal from, e.g., a driver unit, the control electrode may set the IGBT in one of a conducting state and a blocking state.

In some cases, the gate electrode may be included within a trench of the IGBT, wherein the trench may exhibit, e.g., a stripe configuration or a needle configuration.

Further, trenches of an IGBT may integrate different types of electrodes; some of the electrodes may be connected to the IGBT gate terminal, and others may be connected to an IGBT load terminal, e.g., the source/emitter terminal.

It is usually desirable to keep losses, e.g., switching losses, of the IGBT low. For example, low switching losses may be achieved by ensuring short switching durations, e.g., a short turn-on duration and/or a short turn-off duration.

On the other hand, in a given application, there may also be requirements regarding a maximum slope of the voltage (dV/dt) and/or a maximum slope of the load current (dI/dt).

Further, the switching behavior of an IGBT may depend on its operating temperature, wherein it can be desirable to fulfill said provisions regarding power losses and voltage/current slopes within a broad range of possible operating temperatures.

SUMMARY

According to an embodiment, a power semiconductor device comprises an active cell region with a drift region of a first conductivity type; a plurality of IGBT cells at least partially arranged within the active cell region, wherein each of the IGBT cells comprises at least one trench that extends into the drift region along a vertical direction; an edge termination region surrounding the active cell region; a transition region arranged between the active cell region and the edge termination region, the transition region having a width along a lateral direction from the active cell region towards the edge termination region, wherein at least some of the IGBT cells are arranged within, or, respectively, extend into the transition region; and an electrically floating barrier region of a second conductivity type, wherein the electrically floating barrier region is arranged within the active cell region and in contact with at least some of the trenches of the IGBT cells, and wherein the electrically floating barrier region does not extend into the transition region.

According to another embodiment, a power semiconductor device comprises a first load terminal and a second load terminal, the power semiconductor device being configured to conduct a load current along a vertical direction between said terminals and comprising: an active cell region with a drift region of a first conductivity type; an edge termination region having a well region of a second conductivity type; a plurality of IGBT cells arranged within the active cell region, wherein each of the IGBT cells comprises a plurality of trenches that extend into the drift region along the vertical direction and that laterally confine a plurality of mesas. The plurality of trenches include: at least one control trench having a control electrode; at least one dummy trench having a dummy electrode electrically coupled to the control electrode; at least one source trench having a source electrode electrically connected with the first load terminal. The plurality of mesas include at least one active mesa arranged between the at least one control trench and the at least one source trench; and at least one inactive mesa arranged adjacent to the at least one dummy trench. The power semiconductor device further comprises an electrically floating barrier region of the second conductivity type, wherein at least both a bottom of the dummy trench and a bottom of the source trench extend at least partially into the electrically floating barrier region, and wherein a portion of the drift region located in a lateral direction between the electrically floating barrier region and the well region has a lateral extension of at least 1 μm in said lateral direction.

According to another embodiment, a power semiconductor device comprises an active cell region with a drift region of a first conductivity type, a plurality of IGBT cells at least partially arranged within the active cell region, wherein each of the IGBT cells comprises at least one trench that extends into the drift region along a vertical direction, an edge termination region surrounding the active cell region, a transition region arranged between the active cell region and the edge termination region, the transition region having a width along a lateral direction from the active cell region towards the edge termination region, wherein at least some of the IGBT cells are arranged within, or, respectively, extend into the transition region, a barrier region of a second conductivity type, wherein the barrier region is arranged within the active cell region and in contact with at least some of the trenches of the IGBT cells, and wherein the barrier region does not extend into the transition region, and a first load terminal and a second load terminal, the power semiconductor device being configured to conduct a load current along a vertical direction between the first and second load terminals, and wherein each IGBT cell has a micro-pattern-trench structure.

According to yet another embodiment, a method of processing a power semiconductor device is presented. The power semiconductor device comprises an active cell region with a drift region of a first conductivity type; a plurality of IGBT cells at least partially arranged within the active cell region, wherein each of the IGBT cells comprises at least one trench that extends into the drift region along a vertical direction; an edge termination region surrounding the active cell region; and a transition region arranged between the active cell region and the edge termination region, the transition region having a width along a lateral direction from the active cell region towards the edge termination

region, wherein at least some of the IGBT cells are arranged within, or, respectively, extend into the transition region. The method comprises: providing an electrically floating barrier region of a second conductivity type, wherein the electrically floating barrier region is arranged within the active cell region and in contact with at least some of the trenches of the IGBT cells, and wherein the electrically floating barrier region does not extend into the transition region.

According to another embodiment, a further method of processing a power semiconductor device is presented. The power semiconductor device comprises a first load terminal and a second load terminal, the power semiconductor device being configured to conduct a load current along a vertical direction between said terminals and comprising: an active cell region with a drift region of a first conductivity type; an edge termination region having a well region of a second conductivity type; a plurality of IGBT cells arranged within the active cell region, wherein each of the IGBT cells comprises a plurality of trenches that extend into the drift region along the vertical direction and that laterally confine a plurality of mesas. The plurality of trenches include: at least one control trench having a control electrode; at least one dummy trench having a dummy electrode electrically coupled to the control electrode; at least one source trench having a source electrode electrically connected with the first load terminal. The plurality of mesas include at least one active mesa arranged between the at least one control trench and the at least one source trench; and at least one inactive mesa arranged adjacent to the at least one dummy trench. The further method comprises: providing an electrically floating barrier region of the second conductivity type, wherein at least both a bottom of the dummy trench and a bottom of the source trench extend at least partially into the electrically floating barrier region, and a portion of the drift region located in a lateral direction between the electrically floating barrier region and the well region has a lateral extension of at least 1 μm in said lateral direction.

In accordance with a yet further embodiment, a power semiconductor device comprises a first load terminal and a second load terminal. The power semiconductor device is configured to conduct a load current along a vertical direction between said terminals and comprises: a drift region of a first conductivity type; a plurality of IGBT cells, wherein each of the IGBT cells comprises a plurality of trenches that extend into the drift region along the vertical direction and that laterally confine at least one active mesa, the at least one active mesa comprising an upper section of the drift region; and an electrically floating barrier region of a second conductivity type that is spatially confined, in and against the vertical direction, by the drift region. The total volume of all active mesas is divided into a first share and into a second share, the first share not laterally overlapping with the barrier region and the second share laterally overlapping with the barrier region. The first share is configured to carry the load current at least within the range of 0% to 100% of the nominal load current for which the power semiconductor device is designed. The second share is configured to carry the load current if it exceeds at least 0.5% of the nominal load current.

Those skilled in the art will recognize additional features and advantages upon reading the following detailed description, and upon viewing the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The parts in the figures are not necessarily to scale, instead emphasis being placed upon illustrating principles of the invention. Moreover, in the figures, like reference numerals designate corresponding parts. In the drawings:

FIG. **1** schematically and exemplarily illustrates a section of a horizontal projection of a power semiconductor device in accordance with one or more embodiments;

FIGS. **2**, **3**A, **3**B, **4**A, and **4**B each schematically and exemplarily illustrates a section of a vertical cross-section of a power semiconductor device in accordance with one or more embodiments;

FIG. **5** schematically and exemplarily illustrates a course of a dopant concentration in a power semiconductor device in accordance with one or more embodiments;

FIGS. **6**A-**6**C schematically and exemplarily illustrate a section of a vertical cross-section of a power semiconductor device in accordance with one or more embodiments;

FIGS. **7** and **8**A-**8**D each schematically and exemplarily illustrate a section of a horizontal projection of a power semiconductor device in accordance with one or more embodiments;

FIG. **9** schematically and exemplarily illustrate a perspective projection of a power semiconductor device in accordance with one or more embodiments;

FIGS. **10**-**11** each schematically and exemplarily illustrate a section of a vertical cross-section of a power semiconductor device in accordance with one or more embodiments;

FIGS. **12**-**19** each schematically and exemplarily illustrate a section of a horizontal projection of a power semiconductor device in accordance with one or more embodiments; and

FIG. **20** schematically and exemplarily illustrates steps of a method of processing a power semiconductor device in accordance with one or more embodiments.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings which form a part hereof and in which are shown by way of illustration specific embodiments in which the invention may be practiced.

In this regard, directional terminology, such as "top", "bottom", "below", "front", "behind", "back", "leading", "trailing", "below", "above" etc., may be used with reference to the orientation of the figures being described. Because parts of embodiments can be positioned in a number of different orientations, the directional terminology is used for purposes of illustration and is in no way limiting. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims.

Reference will now be made in detail to various embodiments, one or more examples of which are illustrated in the figures. Each example is provided by way of explanation, and is not meant as a limitation of the invention. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the present invention includes such modifications and variations. The examples are described using specific language which should not be construed as limiting the scope of the appended claims. The drawings are not scaled and are for illustrative purposes only. For clarity, the same elements or manufacturing steps have been designated by the same references in the different drawings if not stated otherwise.

The term "horizontal" as used in this specification intends to describe an orientation substantially parallel to a horizontal surface of a semiconductor substrate or of a semiconductor structure. This can be for instance the surface of a semiconductor wafer or a die or a chip. For example, both the first lateral direction X and the second lateral direction Y mentioned below can be horizontal directions, wherein the first lateral direction X and the second lateral direction Y may be perpendicular to each other.

The term "vertical" as used in this specification intends to describe an orientation which is substantially arranged perpendicular to the horizontal surface, i.e., parallel to the normal direction of the surface of the semiconductor wafer/chip/die. For example, the vertical direction Z mentioned below may be an extension direction that is perpendicular to both the first lateral direction X and the second lateral direction Y.

In this specification, n-doped is referred to as "first conductivity type" while p-doped is referred to as "second conductivity type". Alternatively, opposite doping relations can be employed so that the first conductivity type can be p-doped and the second conductivity type can be n-doped.

In the context of the present specification, the terms "in ohmic contact", "in electric contact", "in ohmic connection", and "electrically connected" intend to describe that there is a low ohmic electric connection or low ohmic current path between two regions, sections, zones, portions or parts of a semiconductor device or between different terminals of one or more devices or between a terminal or a metallization or an electrode and a portion or part of a semiconductor device. Further, in the context of the present specification, the term "in contact" intends to describe that there is a direct physical connection between two elements of the respective semiconductor device; e.g., a transition between two elements being in contact with each other may not include a further intermediate element or the like.

In addition, in the context of the present specification, the term "electric insulation" is used, if not stated otherwise, in the context of its general valid understanding and thus intends to describe that two or more components are positioned separately from each other and that there is no ohmic connection connecting those components. However, components being electrically insulated from each other may nevertheless be coupled to each other, for example mechanically coupled and/or capacitively coupled and/or inductively coupled. To give an example, two electrodes of a capacitor may be electrically insulated from each other and, at the same time, mechanically and capacitively coupled to each other, e.g., by means of an insulation, e.g., a dielectric.

Specific embodiments described in this specification pertain to, without being limited thereto, a semiconductor device, such as an IGBT, e.g., exhibiting a stripe cell or cellular cell configuration, e.g., an IGBT that may be used within a power converter or a power supply. Thus, in an embodiment, such IGBT can be configured to carry a load current that is to be fed to a load and/or, respectively, that is provided by a power source. For example, the IGBT may comprise one or more active power semiconductor cells, such as a monolithically integrated IGBT cell, and/or a monolithically integrated RC-IGBT cell. Such transistor cells may be integrated in a power semiconductor module. A plurality of such cells may constitute a cell field that is arranged with an active cell region of the IGBT.

The term "power semiconductor device" as used in this specification intends to describe a semiconductor device on a single chip with high voltage blocking and/or high current-carrying capabilities. In other words, such power semiconductor device (e.g., an IGBT) is intended for high current, typically in the Ampere range, e.g., up to several ten or hundred Ampere, and/or high voltages, typically above 15 V, more typically 100 V and above, e.g., up to at least 1200 V.

For example, the power semiconductor device described below may be IGBT exhibiting a stripe trench cell configuration or a cellular trench cell configuration and can be configured to be employed as a power component in a low-, medium- and/or high voltage application.

For example, the term "power semiconductor device" as used in this specification is not directed to logic semiconductor devices that are used for, e.g., storing data, computing data and/or other types of semiconductor based data processing.

FIG. **1** schematically and exemplarily illustrates a section of a horizontal projection of a power semiconductor device **1** in accordance with one or more embodiments. FIG. **2** schematically and exemplarily illustrates a section of a vertical cross-section of a power semiconductor device **1** in accordance with one or more embodiments. In the following, it will be referred to each of FIG. **1** and FIG. **2**.

The power semiconductor device **1** can be an IGBT or, respectively, a power semiconductor device that has a configuration that is based on an IGBT configuration, such as Reverse Conducting (RC) IGBT.

For example, the power semiconductor device **1** comprises a semiconductor body **10** that is coupled to a first load terminal **11** and a second load terminal **12**. For example, the first load terminal **11** is an emitter terminal, whereas the second load terminal **12** can be a collector terminal.

The semiconductor body **10** may comprise a drift region **100** of the first conductivity type. The drift region **100** may be n-doped. In an embodiment, the drift region **100** has a (electrically activated) dopant concentration within the range of 2e12 cm^{-3} to 4e14 cm^{-3}. For example, the extension of the drift region **100** along the vertical direction Z and its dopant concentration are chosen in dependence of the blocking voltage rating for which the power semiconductor device **1** shall be designed, as it is known to the skilled person. Within the present specification, the term "drift region" is intended to describe such region of a power semiconductor device (e.g., an IGBT) the skilled person typically designates as drift region or, respectively, drift zone.

Further, the first load terminal **11** may be arranged on the frontside of the power semiconductor device **1** and may include a frontside metallization. The second load terminal **12** may be arranged, opposite to the frontside, e.g., on a backside of the power semiconductor device **1** and may include, for example, a backside metallization. Accordingly, the power semiconductor device **1** may exhibit a vertical configuration and the load current may be conducted along the vertical direction Z. In another embodiment, each of the first load terminal **11** and the second load terminal **12** may be arranged on a common side, e.g., both on the frontside, of the power semiconductor device **1**.

Now referring in more detail to FIG. **1**, the power semiconductor device **1** may further include an active cell region **1-2**, an edge termination region **1-3** and a chip edge **1-4**. The edge termination region **1-3** may surround the active cell region **1-2**. A transition region **1-5** can be arranged between the active cell region **1-2** and the edge termination region **1-3**. For example, the transition region **1-5** surrounds the active cell region **1-2**. The transition region **1-5** can be surrounded by the edge termination region **1-3**.

In an embodiment, the semiconductor body **10** essentially consists of the edge termination region **1-3**, the transition region **1-5** and the active cell region **1-2**.

For example, each of the edge termination region **1-3**, the transition region **1-5** and the active cell region **1-2** extend along the vertical direction Z from the frontside of the power semiconductor device **1** entirely through the semiconductor body **10** to the backside of the power semiconductor device **1**. Each of the edge termination region **1-3**, the transition region **1-5** and the active cell region **1-2** may not only include components of the semiconductor body **10**, but also components external thereof, e.g., components of the first load terminal **11** and/or the second load terminal **12**.

Further, in an example, along lateral directions, there is no overlap between the edge termination region **1-3**, the transition region **1-5** and the active cell region **1-2** within the semiconductor body **10**. Thus, the active cell region **1-2** may entirely be surrounded by the transition region **1-5**, and, within the semiconductor body **10**, there is no lateral overlap, e.g., along the first lateral direction X, the second lateral direction Y and linear combinations thereof, between the transition region **1-5** and the active cell region **1-2**. Analogously, the transition region **1-5** may entirely be surrounded by the edge termination region **1-3**, and, within the semiconductor body **10**, there is no lateral overlap, e.g., along the first lateral direction X, the second lateral direction Y and linear combinations thereof, between the transition region **1-5** and the edge termination region **1-3**.

In an embodiment, the transition region **1-5** has a width W along a lateral direction from the active cell region **1-2** towards the edge termination region **1-3** (e.g., in/against the first lateral direction X and in/against the second lateral Y and/or in linear combinations of the these lateral directions) of at least 1 μm. Said width W of the transition region **1-5** may hence be the distance between the active cell region **1-2** and the edge termination region **1-3**. This (minimum) width W may be present along the entire circumference of the transition region **1-5**. The width of the transition region **1-5** may be greater than 1 μm, e.g., greater than 3 μm, greater than 5 μm or even greater than 10 μm. Further exemplary features of the transition region **1-5** and the edge termination region **1-5** will be described below. Along said width W, a portion of the drift region **100** may be present.

The chip edge **1-4** may laterally terminate the semiconductor body **10**, e.g., the chip edge **1-4** may have become into being by means of wafer dicing, for example, and may extend along the vertical direction Z. The edge termination region **1-3** may be arranged between the active cell region **1-2** and the chip edge **1-4**, as illustrated in FIG. **1**.

In the present specification, the terms "active cell region" and "edge termination region" are employed in a regular manner, i.e., the active cell region **1-2** and the edge termination region **1-3** may be configured to provide for the principle technical functionalities the skilled person typically associated therewith.

For example, the active cell region **1-2** of the power semiconductor device **1** is configured to conduct the main part of the load current between the terminals **11**, **12**, whereas the edge termination region **1-3** does not conduct the load current, but rather fulfills functions regarding the course of the electric field, ensuring the blocking capability, safely terminating the active cell region **1-2** and the transition region **1-5** and so forth, in accordance with an embodiment.

The power semiconductor device **1** comprises a plurality of IGBT cells **1-1**, wherein the plurality of IGBT cells **1-1** is predominantly arranged within the active cell region **1-2**. For example, most of the plurality of IGBT cells **1-1** of the power semiconductor device **1** are arranged within the active cell region **1-2**. The number of IGBT cells **1-1** may be greater than 100, than 1000, or even greater than 10,000. For example, at least 85%, at least 95% or at least 98% of the total number of IGBT cells **1-1** are arranged within the active cell region **1-2**. In an embodiment, the remaining IGBT cells **1-1** are arranged within the transition region **1-5**. Some of the IGBT cells **1-1** may entirely be arranged within the transition region **1-5**, others may be arranged with both within the active cell region **1-2** and extend, by means of their respective lateral ends, into the transition region, as schematically illustrated in FIG. **1**.

In an embodiment, each IGBT cell **1-1** at least partially extends into the transition region **1-5**, as schematically and exemplarily illustrated in FIG. **1**.

Thus, for example, some of the IGBT cells **1-1** are arranged within the transition region **1-5** or, respectively, extend into the transition region **1-5**, as schematically and exemplarily illustrated in FIG. **1**. In this respect, the transition region **1-5** can also be understood as a form of an active region of the power semiconductor device **1**. For example, by means of said share of the total number of IGBT cells **1-1** that is arranged within the transition region **1-5** or that extends into the transition region **1-5**, the transition region **1-5** may also be configured to conduct a part of the load current.

In accordance with an embodiment, the IGBT cells **1-1** are not arranged within the edge termination region **1-3**. However, within the edge termination region **1-3**, specially configured charge carrier drainage cells (not illustrated in FIG. **1**, cf. FIG. **6**A-B) may be included that support drainage of charge carriers, e.g., shortly before and/or during a turn-off operation.

Each IGBT cell **1-1** may exhibit a stripe configuration as schematically illustrated in FIG. **1**, wherein the total lateral extension in one lateral direction, e.g., along with the second lateral direction Y, of each IGBT cell **1-1** and its components may substantially correspond to, or, respectively, slightly exceed the total extension of the active cell region **1-2** along this lateral direction.

In another embodiment, each IGBT cell **14** may exhibit a cellular configuration, wherein the lateral extensions of each IGBT cell **1-1** may be substantially smaller than the total lateral extensions of the active cell region **1-2**.

However, embodiments described herein rather relate to IGBT cells **1-1** having a stripe configuration with respect to the second lateral direction Y, as exemplarily and schematically illustrated in most of the drawings.

In an embodiment, each of the plurality of IGBT cells **1-1** that are included in the active cell region **1-2** exhibit the same set-up. A section of an exemplary IGBT cell set-up will now be described with respect to FIG. **2**.

The configuration of the IGBT cells **1-1** that may be included within the transition region **1-5** can be identical to the configuration of the IGBT cells **1-1** that are included in the active cell region **1-2**. Additionally or alternatively, the transition region **1-5** includes IGBT cells that have a different configuration, e.g., in terms of the MPT contacting scheme/neighborhood relation (cf. more detailed explanations below), as compared to the IGBT cells **1-1** of the active cell region **1-2**.

Each IGBT cell **1-1** comprises at least one trench that extends into the drift region along the vertical direction Z. Each IGBT cell **1-1** may extend at least partially into the semiconductor body **10** and comprise at least a section of the drift region **100**. Further, each IGBT cell **1-1** may be

electrically connected with the first load terminal **11**. Each IGBT cell **1-1** may be configured to conduct a part of the load current between said terminals **11** and **12**, and to block a blocking voltage applied between said terminals **11** and **12**.

For controlling the power semiconductor device **1**, each IGBT cell **14** may be equipped with a control electrode **141** included in a control trench **14** and configured to selectively set the respective IGBT cell **1-1** into one of the conducting state and the blocking state.

For example, referring to the example illustrated in FIG. **2**, a source region **101** of the first conductivity type may be electrically connected with the first load terminal **11**. The source region **101** may be n-doped, e.g., at a significantly greater dopant concentration as the drift region **100**.

Further, a channel region **102** of the second conductivity type may separate the source region **101** and the drift region **100**, e.g., the channel region **102** can isolate the source region **101** from the drift region **100**, as it is known to skilled person acquainted with general principles of IGBT configurations. The channel region **102** may be p-doped, e.g. with an electrically activated dopant concentration within the range of 1e15 cm^{-3} to 5e18 cm^{-3}. A transition between the channel region **102** and the drift region **100** may form a first pn-junction **1021**.

For connecting the source regions **101** with the first load terminal **11**, first contact plugs **113** can extend from the first load terminal **11** along the vertical direction Z so as to contact each of the source region **101** and the channel region **102**.

The drift region **100** may extend along the vertical direction Z until it interfaces with a doped contact region **108** that is arranged in electrical contact with the second load terminal **12**. The section of the drift region **100** arranged between region **105** (explained in more detail below) and the doped contact region **108** may form the major part of the drift region **100**. In an embodiment, the dopant concentration of the drift region **100** increases in the lower section of the drift region **100** that forms the interface with the doped contact region **108**, e.g., so as to form the field stop region of the first conductivity type, as it is known to the skilled person.

The doped contact region **108** may be formed in accordance with the configuration of the power semiconductor device **1**; e.g., the doped contact region **108** can be an emitter region of the second conductivity type, e.g., a p-type emitter. For forming an RC-IGBT, the doped contact region **108** may be constituted by an emitter region of the second conductivity type that is interrupted by small sections of the first conductivity type that are also electrically connected to the second load terminal **12** and which are commonly referred to as “n-shorts”.

For example, each IGBT cell **1-1** includes at least one control trench **14** having said control trench electrode **141** and at least one dummy trench **15** having a dummy trench electrode **151**, wherein each of said trenches **14**, **15** may extend into the semiconductor body **10** along the vertical direction Z and include an insulator **142**, **152** that insulates the respective trench electrode **141**, **151** from the semiconductor body **10**.

The trench electrodes **141**, **151** of the at least one control trench **14** and of the at least one dummy trench **15** may each be electrically coupled to a control terminal **13** of the power semiconductor device **1**, in accordance with an embodiment.

Whereas FIG. **2** exemplarily illustrates that the dummy trench **15** is arranged adjacent to the control trench **14**, it shall be understood that the IGBT cell **1-1** may comprise one or more further trenches of a type different from the control trench type and the dummy trench type, and that this at least one further trench may be arranged adjacent to the control trench **14**. For example, said at least one further trench can be a source trench (reference numeral **16** in other drawings) whose trench electrode (reference **161** in other drawings) is electrically connected to the first load terminal **11**. This will be explained in more detail below.

For example, the control terminal **13** is a gate terminal. Further, the control terminal **13** may be electrically connected to the control trench electrode **141** and electrically insulated from the first load terminal **11**, the second load terminal **12** and the semiconductor body **10**, e.g., by means of at least an insulation structure **132**.

In an embodiment, the power semiconductor device **1** may be controlled by applying a voltage between the first load terminal **11** and the control terminal **13**, e.g., so as to selectively set the power semiconductor device **1** into one of the conducting state and the blocking state.

For example, the power semiconductor device **1** is configured to be controlled based on a gate-emitter-voltage V_{GE}, e.g., in a principle manner of controlling an IGBT known to the skilled person.

In an embodiment, the dummy trench electrode **151** may also be electrically connected to the control terminal **13** and thus receive the same control signal as the control trench electrode **141**. In another embodiment, the dummy trench electrode **151** may be electrically coupled to the control terminal **13** by means of a resistor having a resistance within the range of $1e^{-3}$ Ohm to 1 Ohm, within the range of 1 Ohm to 10 Ohm, or within the range of 10 Ohm to 100 Ohm. In another embodiment, the dummy trench electrode **151** is electrically connected to a second control terminal (not illustrated) and thus receives a control signal different from control trench electrode **141**.

Further, each IGBT cell **1-1** of the power semiconductor device **1** may have at least one active mesa **18** electrically connected to the first load terminal **11**, the active mesa **18** comprising the source region **101**, the channel region **102** and a part of the drift region **100**, wherein, in the active mesa **18**, respective sections of these regions **101**, **102**, **100** can be arranged adjacent to a sidewall **144** of the control trench **14**, as exemplarily illustrated in FIG. **2**. For example, each of the source region **101** and the channel region **102** are electrically connected to the first load terminal **11**, e.g., by means of the first contact plug **113**.

In an embodiment of the power semiconductor device **1**, the doped contact region **108** is a p-type emitter, and the active mesa **18** may entirely laterally overlap with the p-type emitter **108**.

Further, the control trench electrode **141** (herein also referred to as control electrode **141**) can be configured to receive a control signal from the control terminal **13** and to control the load current in the active mesa **18**, e.g., by inducing an inversion channel in the channel region **102** so as to set the power semiconductor device **1** into the conducting state. Thus, a transition **181** between the first load terminal **11** and the active mesa **18** may provide for an interface for the load current to pass from the first load terminal **11** into the semiconductor body **10** and/or vice versa.

In an embodiment, the inversion channel in the active mesa **18** may be induced once an inversion channel threshold voltage, e.g., within the respective active mesa **18**, is exceeded. For example, the inversion channel threshold voltage depends on at least one of the work function of the control electrode **141**, the dopant concentration of the source region **101**, the dopant concentration of the channel region

102, the relevant thickness of the trench insulator 142, the dielectric constant of the trench insulator 142.

In an embodiment, all active mesas 18 of the power semiconductor device 1 are configured with the same inversion channel threshold voltage.

For example, the control electrodes 141 of all IGBT cells 1-1 that are included in the active cell region 1-2 may be electrically connected to the control terminal 13.

In addition to the active mesa 18, each IGBT cell 1-1 of the power semiconductor device 1 can have at least one inactive mesa 19, e.g., arranged adjacent to the at least one dummy trench 15, wherein a transition 191 between the first load terminal 11 and the inactive mesa 19 provides an electrical insulation at least for charge carriers of the first conductivity type.

In an embodiment, the IGBT cell 1-1 may be configured to prevent the load current from crossing said transition 191 between the inactive mesa 19 and the first load terminal 11. For example, the inactive mesa 19 does not allow for inducing an inversion channel. In contrast to the active mesa 18, the inactive mesa 19 does not conduct the load current during the conducting state of the power semiconductor device 1, in accordance with an embodiment. For example, the inactive mesa 19 can be considered as a decommissioned mesa that is not used for the purpose of carrying the load current.

In a first embodiment of the inactive mesa 19, the inactive mesa 19 is not electrically connected to the first load terminal 11, but electrically insulated from, e.g., by means of an insulation layer 112. In this embodiment, the transition 191 between the first load terminal 11 and the inactive mesa 19 provides an electrical insulation not only for charge carriers of the first conductivity type, but also for charge carriers of the second conductivity type. To this end, in a variant the inactive mesa 19 comprises neither section of the source region 101 nor a section of the channel region 102 nor is the inactive mesa 19 contacted by means of a contact plug (cf. reference numeral 111), as illustrated in FIG. 2. In another variant, the inactive mesa 19 may be configured in a similar manner as the active mesa 18, e.g., by also comprising a section of the source region 101 and/or a section of the channel region 102, the difference to the active mesa 18 including that neither the section of the source region 101 (if present) nor the section of the channel region 102 of the inactive mesa 19 is electrically connected to the first load terminal 11. In accordance with the first embodiment of the inactive mesa 19, no current at all crosses said transition 191.

In a second embodiment of the inactive mesa 19, the inactive mesa 19 may be electrically connected to the first load terminal 11, wherein the transition 191 between the first load terminal 11 and the inactive mesa 19 provides an electrical insulation only for charge carriers of the first conductivity type, but not for charge carrier of the second conductivity type. In other words, in this second embodiment, the inactive mesa 19 may be configured at allow a current of charge carriers of the second conductivity type, e.g., a hole current, to pass said transition 191. For example, depending on the electrical potential of the dummy trench electrode 151, such hole current may only temporarily come into being, e.g., shortly before carrying out a turn-off operation, e.g., so as to reduce the total charge carrier concentration present in the semiconductor body 10. In an embodiment, this may also occur for such inactive mesas 19 with an electrical insulation only for charge carries of the first conductivity type in a reverse conducting IGBT configuration, where the load current would be temporarily carried through these inactive mesas 19 in diode mode operation, where the backside (cf. doped contact region 108) would be structured to comprise both emitters of the second conductivity type and emitters of the first conductivity type (previously referred to as "n-shorts"). As stated above, in this second embodiment, the inactive mesa 19 may be electrically connected to the first load terminal 11. For example, a doped contact region (not illustrated) of the second conductivity type (that is different from the electrically floating barrier region 105 mentioned below) of the inactive mesa 19 may be electrically connected to the first load terminal 11, e.g., by means of one of the first contact plugs 113, as schematically and exemplarily illustrated in FIG. 3B. The doped contact region (not illustrated) of the second conductivity type may isolate the section of the drift region 100 that is present within the inactive mesa 19 from the first load terminal 11. For example, in accordance with the second embodiment of the inactive mesa 19, within the inactive mesa 19, there is no region doped with dopants of the first conductivity type that is electrically connected to the first load terminal 11.

The above illustrated first embodiment and second embodiment of the inactive mesa 19 may allow for providing the configuration of the IGBT cell 1-1 to prevent the load current from crossing said transition 191 between the inactive mesa 19 and the first load terminal 11.

The inactive mesa 19 may be laterally confined by the control trench 14 and the dummy trench 15, or by the dummy trench 15 and another trench type, which will be elucidated further below. Further optional aspects of the inactive mesa 19 will be described below. For example, even though the dummy trench electrode 151 may be electrically connected to the control terminal 13, in an example, the dummy trench electrode 151 is not configured to control the load current in the inactive mesa 19, since the inactive mesa 19 does not allow for inducing an inversion channel within the inactive mesa 19, in accordance with an embodiment.

The power semiconductor device 1 may further comprise an electrically floating barrier region 105 of the second conductivity type (in the following also simply referred to as "barrier region"), as schematically exemplarily illustrated in FIG. 2. Exemplary features of this barrier region 105 will be explained in greater detail further below. Before the more detailed description of the barrier region 105, exemplary aspects regarding a Micro-Pattern-Trench-Structure (MPT) of the power semiconductor device 1 shall be explained.

Referring to the embodiments schematically illustrated in FIGS. 3A-B, each IGBT cell 1-1 of the active cell region 1-2 may further comprise at least one source trench 16 that extends into the semiconductor body 10 along the vertical direction Z and includes an insulator 162 that insulates a source trench electrode 161 from the semiconductor body 10, the source trench electrode 161 being electrically connected to the first load terminal 11. For example, the at least one source trench 16 is arranged between the control trench 14 and the dummy trench 15, as illustrated in FIGS. 3A-B. In an embodiment, each IGBT cell 1-1 may comprise more than one source trench 16, e.g., two source trenches 16 (cf. FIG. 4A) or four source trenches 16 (cf. FIG. 6A), wherein each of the trench electrodes 161 of the source trenches may be electrically connected to the first load terminal 11. For example, the more than one source trenches 16 are arranged between the control trench 14 on the one side and the dummy trench 15 on the other side.

In an embodiment, the active mesa 18 may be laterally confined by the control trench 14 and the source trench 16. For example, the sidewall 144 of the control trench 14 and

a sidewall **164** of the source trench **16** confine the active mesa **18** along the first lateral direction X. The active mesa **18** may be configured in a manner that has exemplarily described with respect to FIG. **2**; e.g., the first contact plug **113** may electrically connect each of the section of the channel region **102** and the section of the source region **101** to the first load terminal **11**.

Further, in accordance with the embodiment illustrated in FIGS. **3**A-B and **4**A-B, each IGBT cell **1-1** of the active cell region **1-2** may comprise more than one inactive mesas **19**, wherein at least one of the inactive mesas **19** can be laterally confined by the source trench **16** and the dummy trench **15**. Another inactive mesa **19** can be laterally confined by two source trenches **16**. Another inactive mesa **19** can be laterally confined by two dummy trenches **15**. Yet another inactive mesa **19** can be laterally confined by one of the dummy trenches **15** and the control trench **14**. As illustrated, each of the inactive mesas **19** may comprise a respective section of the channel region **102**, wherein, in an embodiment, these sections are not electrically connected to the first load terminal **11** but electrically insulated them from, e.g., by means of the insulation layer **112**, as has been explained above.

Referring to the embodiment schematically illustrated in FIGS. **3**A-B, each IGBT cell **1-1** of the active cell region may further comprise, in addition to or as an alternative to the at least one source trench **16**, at least one floating trench **17** that extends into the semiconductor body **10** along the vertical direction Z and includes an insulator **172** that insulates a trench electrode **171** from the semiconductor body **10**, the trench electrode **171** of the floating trench **17** being electrically floating. In an embodiment, the trench electrode **171** of the floating trench **17** is neither electrically connected to the first load terminal **11**, nor electrically connected to the second load terminal **12**, nor electrically connected to the control terminal **13**, nor to a section of the semiconductor body **10**.

In an embodiment, the electrically floating trench electrode **171** is connected, by means of a connection having a high ohmic resistance, to a defined electrical potential (e.g., to an electrical potential of a contact or to an electrical potential of another semiconductor region). For example, by means of said high ohmic connection, during a switching operation, the electrical potential of the electrically floating trench electrode **171** is temporarily decoupled from the defined electrical potential. Said decoupling may occur on a time scale of said switching operation, e.g., for at least 10 ns, or at least 100 ns, or at least 10 μs. For example, the resistance of said high ohmic connection amounts to more than 1e2Ω, or to more than 1 e6Ω. In an embodiment, an ohmic resistance, e.g. measured during a standstill situation, between the first load terminal **11** and the electrically floating trench electrode **171** amounts to more than 1e2Ω, or to more than 1 e6Ω.

For example, if present, the at least one floating trench **17** can be arranged between the control trench **14** and the dummy trench **15**. Further, as illustrated in FIGS. **3**A-B, the IGBT cell **1-1** may additionally comprise said at least one source trench **16**, wherein the source trench **16** and the floating trench **17** may be arranged between the control trench **14** on the one side and the dummy trench **15** on the other side. In an embodiment, the active mesa **18** is laterally confined by the sidewall **144** of the control trench **14** and the sidewall **164** of the source trench **16**. The inactive mesa **19** may be laterally confined by at least two of the group of the sidewall **164** of the source trench **16**, the sidewall **174** of the floating trench **17**, and the sidewall **154** of dummy trench **15**.

Thus, in accordance with an embodiment, each IGBT cell **1-1** of the active region comprises at least one control trench **14**, at least one dummy trench **15**, at least one source trench **16** and, optionally, at least one floating trench **17**, wherein the at least one source trench **16** and (if present) the at least one floating trench **17** (if present) can be arranged between the control trench **14** and the dummy trench **15**.

In an embodiment, the power semiconductor device **1** can be an IGBT and each of its IGBT cells **1-1** of its active region **1-2** may exhibit a micro pattern trench (MPT) structure.

For example, each or at least most of the trenches **14**, **15**, **16**, **16**, **17** that may be included in the IGBT cell **1-1** may exhibit equal spatial dimensions and may be arranged in accordance with a regular pattern. For example, each of the trenches **14**, **15**, **16**, **16**, **17** may exhibit a depth along the vertical direction Z within the range of 3 μm to 8 μm, and a width along the first lateral direction X within the range of 0.4 μm to 1.6 μm. The trenches **14**, **15**, **16**, **17** can be formed according to a first layout having a first pitch, wherein the first layout may define each of the trench widths and the mesa widths.

Further, each or at least most of the trench electrodes **141**, **151**, **161**, **171** of all trenches **14**, **15**, **16**, **16**, **17** that may be included in the IGBT cell **1-1** may exhibit equal spatial dimensions, e.g., regarding the total extension along the vertical direction (which is terminated by means of the respective trench bottoms **145**, **155**, **165**, **175**) and the total extension in the first lateral direction (i.e., the trench width, which is terminated by means of the respective sidewalls **144**, **154**, **164**, **174**), and/or regarding the dimensions of the insulators **142**, **152**, **162**, **172**. In addition, each of the trenches **14**, **15**, **16**, **16**, **17** that may be included in the IGBT cell **1-1** can be arranged equidistantly along the first lateral direction X. For example, each of the mesas **18** and **19** of the IGBT cell **1-1** may exhibit the same width, which may be within the range of 0.1 μm to 0.3 μm, within the range of 0.3 μm to 0.8 μm, or within the range of 0.8 μm to 1.4 μm.

Further, some of the trenches **14**, **15**, **16**, **16**, **17** that may be included in the IGBT cell **1-1** may extend into the barrier region **105**, e.g., by at least 100 nm, by at least 500 nm or by at least 1000 nm. This aspect will also be explained in greater detail below.

For the following explanations, these abbreviations may apply:

G=control trench **14**
D=dummy trench **15**
S=source trench **16**
F=floating trench **17**
k=active mesa **18**
o=inactive mesa **19**

As has been stated above, the power semiconductor device **1** may comprise a plurality of equally configured IGBT cells **1-1** within the active cell region **1-2**. In an embodiment, using the abbreviations introduced above, an exemplary neighborhood relationship within in each IGBT cell **1-1** of the active cell field **1-2** may be expressed as follows:

oDoSoSkGkSoSoD

Without being limited to this exemplary neighborhood relationship (which is also being referred to as contacting scheme herein), the embodiments according to most of the remaining drawings are based on the above identified exemplary neighborhood relationship. Thus, it shall be understood that the IGBT cells **1-1** must not necessarily comprise a floating trench **17**, in accordance with an embodiment.

For example, in another embodiment, each of the IGBT cells **1-1** only comprise one or more control trenches **14** and one or more source trenches **16**. Further, in such embodiment, each of the IGBT cells **1-1** only comprises one or more active mesas **18**, but no inactive mesas **19**. E.g., the contacting scheme may then be "kGkS" or the like. Then, every trench electrode connected to the control terminal **13** would indeed control an active mesa, e.g., by controlling a respective inversion channel and there would hence no dummy trenches. In yet another embodiment, the IGBT cells **1-1** only comprise one or more control trenches **14** and one or more active mesas, but neither inactive mesas nor a dummy trench, nor a source trench, nor a floating trench.

As indicated above, irrespective of the contacting scheme, the power semiconductor device **1** may further comprise an electrically floating barrier region **105** of the second conductivity type (in the following also simply referred to as "barrier region").

In an embodiment, the barrier region **105** is configured to provide for an electrically conductive path between a section of the active mesa **18** and the bottom **155** of the dummy trench **15**. Thus, the barrier region **105** may be configured to guide the electrical potential of the section of the active mesa **18** to the bottom **155** of the dummy trench **15**. For example, the barrier region **105** may extend into the active mesa **18** and from there below the bottom **165** of the source trench **16** and across the inactive mesa **19** so as to interface with the bottom **155** of the dummy trench **15**.

As has been stated above, the power semiconductor device **1** may comprise a plurality of IGBT cells **1-1**, e.g., most of them included in the active cell region **1-2**. For example, the barrier region **105** connects the inactive mesas **19** included in the plurality of IGBT cells **1-1** within the active region **1-2** with each other. For example, to this end, the barrier region **105** may extend partially into each of the inactive mesas **19**. The barrier region **105** may further extend, at least partially, into some of the active mesas **18**. Each of the dummy trench bottoms **155** may extend into the barrier region **105**. Thereby, the barrier region **105** can guide the electrical potential present within the active mesas towards the dummy trench electrodes **151**.

As will be explained in more detail below, the barrier region **105** may laterally overlap with some (parts) of the active mesas **18** and may not laterally overlap with other (parts) of the active mesas **18**. For example, to this end, the barrier region **105** may exhibit a lateral structure formed by one or more passages **1053**, as will be explained in more detail below, and/or the barrier region **105** may be laterally displaced from the edge termination region **1-3** by means of the transition region **1-5** that may (as explained above) be equipped with one or more active mesas **18**.

Hence, in more general terms, in accordance with an embodiment, a power semiconductor device **1** is presented that comprises the first load terminal **11** and the second load terminal **12**. The power semiconductor device **1** is configured to conduct the load current along the vertical direction Z between said terminals **11**,**12** and comprises: the drift region **100** of the first conductivity type; the plurality of IGBT cells **1-1**, wherein each of the IGBT cells **1-1** comprises a plurality of trenches (e.g., **14**, **15**, **16**) that extend into the drift region **100** along the vertical direction Z and that laterally confine the at least one active mesa **18**, the at least one active mesa **18** comprising an upper section **100-1** of the drift region **100**. The electrically floating barrier region **105** of the second conductivity type that is spatially confined, in and against the vertical direction Z, by the drift region **100**.

The total volume of all active mesas **18** can be divided into a first share and into a second share, the first share not laterally overlapping with the barrier region **105** and the second share laterally overlapping with the barrier region **105**. For example, the first share of the active mesas **18** laterally overlaps with the at least one passage **1053** (cf. explanations further below) of the barrier region **105** or with another section of the drift region **100** where the barrier region **105** is not present (e.g., within the transition region **1-5**). In contrast, the second share of the active mesas **18** laterally overlaps with the barrier region **105**. For example, the load current conducted by the second share traverses the barrier region **105**.

In an embodiment, the first share is configured to carry the load current at least within the range of 0% to 100% of the nominal load current for which the power semiconductor device is designed. The second share may be configured to carry the load current if it exceeds at least 0.5% of the nominal load current.

Hence, the first share of active mesas **18** can be considered as an "ignition volume" which, e.g., during turn-on of the power semiconductor device **1** starts to conduct the load current whereas the second share initially remains inactive. Then, if, e.g., only if the load current exceeds a threshold of, e.g., at least 0.5% of the nominal load current (wherein this threshold can be higher than 0.5%, e.g., higher than 1%, e.g., at least 5% or at least 10%), the barrier region **105** may become more conductive such that the second share may also carry the load current.

For example, for small load currents below 10%, or below 1%, or below 0.5% of the nominal load current of the power semiconductor device **1**, the active mesas **18** without lateral overlap with barrier region **105** (i.e., said first share of the total volume) may act as emitters of charge carriers of the first conductivity type, and, e.g., by this avoid a snapback in the transfer or output characteristics of the power semiconductor device **1**. For larger load currents (greater than 0.5%, than 1%, than 5% or than 10% of the nominal load current) the upper pn-junction **1051** is in a forward bias mode with respect to the charge carriers of the first conductivity type. This may then allow also for charge carriers of the first conductivity type to be emitted by the active mesas **18** laterally overlapping with the barrier region **105** (i.e., said second share of the total volume).

As already explained above, each active mesa **18** can be configured to induce an inversion channel within the respective active mesa **18**. For example, all active mesas **18** are configured with the same inversion channel threshold voltage. Thus, the delay between the begin of the load current conduction within the second volume share and the begin of the load current conduction within the first volume share (according to which, e.g., during turn-on, the second volume share of the active mesas **18** that laterally overlaps with the barrier region **105** only carries the load current once the load current exceeds said threshold value of, e.g., at least 0.5%) exemplarily described above is, e.g., neither caused by means of providing a control signal to the control electrodes controlling the first volume share different from a control signal provided to the control electrodes controlling the second volume share, nor by a difference between inversion channel threshold voltages. Rather, the first volume share and the second volume share are provided with the same control signal and are configured with the same inversion channel threshold voltage and said delay is achieved only by accordingly positioning and/laterally structuring the barrier region **105**, in accordance with an embodiment.

Hence, in an embodiment, the only differentiating feature between the first volume share of the active mesas **18** and the second volume share of the active mesas **18** is that the first volume share does not laterally overlap with the barrier region **105** and that the second volume share does laterally overlap with the barrier region **105**. For example, thereby, the said exemplarily described delay between the load current conduction begins (starting times) is achieved.

For example, once the load current is conducted by both volume shares, it may be distributed among the volume shares in accordance with the ratio between the volume shares. In an embodiment, if the load current exceeds 50% of the nominal load current, the ratio between a first load current share conducted by the first volume share of the active mesas **18** and a second load current share conducted by the second volume share of the active mesas **18** can be at least within 10% of the ratio between the first volume share and the second volume share or, respectively, the ratio between the first load current share conducted by the first volume share of the active mesas **18** and the second load current share conducted by the second volume share of the active mesas **18** can be (at least substantially) identical to the ratio between the first volume share and the second volume share.

The electrically floating barrier region **105** can be spatially confined, in and against the vertical direction Z, by the drift region **100**. Hence, the barrier region **105** may form each of an upper pn-junction **1051** and a lower pn-junction **1052** with the drift region **100**, wherein the lower pn-junction **1052** can be arranged lower than each of the bottom **155** of the dummy trench **15**. For example, the upper pn-junction **1051** is arranged within the inactive mesa(s) **19** and, hence, above the bottom **155** of the dummy trench **15**. The distance between the first pn-junction **1021** and the upper pn-injunction **1051** along the vertical direction Z may amount to at least 0.5 μm. Thus, the two pn-junctions **1021** and **1051** are not identical to each other, but separated from each other by means of the drift region **100**, in accordance with an embodiment.

In other words, the barrier region **105** may be separated from the channel region **102** by means of at least a part of the drift region **100**. For example, the barrier region **105** is confined, along the vertical direction Z, by an upper section **100-1** of the drift region **100** on the one side and by a lower section **100-2** of the drift region **100** on the other side, wherein said upper section **100-1** forms a transition to the channel regions **102** of the IGBT cells **1-1**. The lower section **100-2** may extend along the vertical direction Z until it interfaces with the doped contact region **108**, which may be, as illustrated above, a p-type emitter.

In an embodiment, the barrier region **105** is not in contact with any other semiconductor region of the second conductivity type, but separated therefrom, e.g., by means of section(s) of the drift region **100**. For example, the distance between the barrier region **105** to the closest other semiconductor region of the second conductivity type amounts to at least 1 μm or to at least 2 μm. Thus, for example, there is no p-type connection between the channel regions **102** and the barrier region **105**, nor is there a p-type connection between the barrier region **105** and a well region **109** of the edge termination region **109** (mentioned further below). Along said distance, a portion of the drift region **100** may be present.

With respect to all embodiments discussed above, it shall be understood that, in accordance with a variant, the sections of the drift region **100** that are included in the mesas **18** and **19**, e.g., the upper sections **100-1** forming the first pn-junction **1021** with the channel region **102** and the upper pn-junction **1051** with the barrier region **105** (cf. explanations below), may exhibit a dopant concentration at least twice as great as compared to the dopant concentration of the section of the drift region **100** arranged below the barrier region **105**, e.g., said lower section **100-2** of the drift region **100** that forms the lower pn-junction **1052** with the barrier region **105**.

Said sections (upper sections **100-1**) of the drift region **100** that are included in the mesas **18** and **19** may each exhibit a maximum dopant concentration within the range of 1e14 cm^{-3} to 4e17 cm^{-3}, e.g., a maximum dopant concentration of at least 1e16 cm^{-3}. For example, said sections of the drift region **100** that are included in the mesas **18** and **19** and that may exhibit said increased dopant concentrations can be referred to as "n-barrier regions". For example, the dopant concentration of the sections of the drift region **100** that are included in the mesas **18** and **19** is chosen such that the upper pn-junction **1051** remains at a level slightly above the trench bottoms **145** and **155**.

Now referring to FIG. **4**B, in accordance with a variant, the increased dopant concentration in the upper section (section **100-1**) of the drift region **100** is only locally provided. For example, only one of the active mesas **18**, or only several of the active mesas **18**, or only all of the active mesas **18** comprise a local n-barrier region **100-3**. For example, each of the local n-barrier regions **100-3** is arranged above the barrier region **105** or, respectively, the barrier region passage **1053**, and below the respective channel region **102**. For example, each n-barrier region **100-3** is arranged in contact with the respective channel region **102** and extends from there down along the vertical direction Z until it interfaces with the (p-) barrier region **105** or, respectively, terminates at a corresponding Z-level if (p-) barrier **105** is absent/exhibits a passage **1053** at the respective location. Along the first lateral direction X, each n-barrier region **100-3** may fill the respective active mesa **18**. Each n-barrier region **100-3** may exhibit a maximum dopant concentration at least twice as great as the dopant concentration of the lower section **100-2** of the drift region **100**. For example, each n-barrier region **100-3** exhibits a maximum dopant concentration within the range of 1e14 cm^{-3} to 4e17 cm^{-3}, e.g., a maximum dopant concentration of at least 1e16 cm^{-3}. In contrast, in accordance with this variant, the upper section **100-1** of the drift region included in the inactive mesas **19** may exhibit a maximum dopant concentration substantially equal to the maximum dopant concentration of the lower section **100-2** of the drift region **100**; e.g., there are no n-barrier regions **100-3** provided within the inactive mesas **19**.

In a variant (not illustrated), the upper pn-junction **1051** may even be arranged lower than each of the bottom **155** of the dummy trench **15** and said bottom **145** of the control trench **14** (wherein this example is not illustrated). In that case, a distance along the vertical direction Z between the bottom **155** of the dummy trench **15** and the upper pn-junction **1051** can be smaller than 3 μm, smaller than 2 μm, or even smaller than 1 μm.

For example, the barrier region **105** exhibits a thickness along the vertical direction Z within the range of 0.1 μm to 0.5 μm, within the range of 0.5 μm to 1 μm, or within the range of 1 μm to 5 μm.

The common vertical extension range along the vertical direction Z between the barrier region **105** the trenches that extend into the barrier region **105** maybe within the range of 50 nm to 3000 nm, for example. In an embodiment, the barrier region **105** extends further along the vertical direc-

tion Z (i.e., down to a deeper level within the semiconductor body **10**) as compared to all or, respectively, at least most of the trenches.

The barrier region **105** may exhibit a resistivity of more than 10 Ωcm and of less than 1000 Ωcm, e.g., of more than 100 Ωcm and of less than 500 Ωcm, in accordance with an embodiment.

The barrier region **105** may include at least one of boron (B), aluminum (Al), difluoroboryl (BF_2), boron trifluoride (BF_3), or a combination thereof. A respective one of these exemplary materials may serve as the dopant material, in accordance with an embodiment. Further, a respective one of these exemplary materials can be implanted into the semiconductor body **10** so as to form the barrier region **105**.

For example, the barrier region **105** exhibits an electrically activated dopant concentration greater than 1e14 cm^{-3} and smaller than 4e17 cm^{-3}. Said dopant concentration, e.g., amounting to approximately 1e16 cm^{-3}, may be present with an extension along the vertical direction Z of at least 0.5 μm, or of at least 1 μm. Further, the barrier region **105** may exhibit a maximum dopant concentration in a region where the bottom **155** of the dummy trench **15** extends into the barrier region **105**.

In an embodiment, the dopant concentration of the barrier region **105** is smaller than the dopant concentration present in the channel regions **102**. For example, the maximal dopant concentration of the barrier region **105** is within the range of 1% to 80% of the dopant concentration present in the channel region **102**.

An exemplary course of the dopant concentration (CC) of dopants of the second conductivity type along the vertical direction Z is illustrated in FIG. **5**, wherein the solid line indicates of dopant concentration the second conductivity type (N_A) and the dotted line the indicates of dopant concentration the first conductivity type (N_D). Accordingly, in an upper section, e.g., in proximity to the first load terminal **11**, the dopant concentration N_A may be comparatively high so as to provide for the channel region **102** (that is not or is not electrically connected to the first load terminal in case of the inactive mesa **19**, depending on the configuration of the inactive mesa **19**, as explained above). The dopant concentration N_A then decreases rapidly in a section of the mesa where the drift region **100** (said upper section **100-1**) is present. The transition between the channel region **102** and the upper section **100-1** of the drift region **100** may form said first pn-junction **1021** within the respective mesa. In case the inactive mesa **19** does not comprise a section of the channel region **102**, the value of the dopant concentration CC between the beginning at the first load terminal **11** and the beginning of the barrier region **105** would accordingly be at the value corresponding to the local minimum LM illustrated in FIG. **5**, or lower. Then, e.g., before the respective trench bottom **155**, the dopant concentration N_A increases (again) so as to form the barrier region **105**. The transition with between the upper section **100-1** of the drift region **100** and the barrier region **105** forms the upper pn-junction **1051**. As illustrated, the barrier region **105** may exhibit its dopant concentration maximum CCM at the depth level being substantially identical to the level where the respective trench terminates, e.g., at the level of the bottom **155** of the dummy trench **15**. The dopant concentration N_A then decreases again so to form the lower pn-junction **1052** with the lower section **100-2** of the drift region **100**.

For example, the electrically floating barrier region **105** is not electrically connected with a defined electrical potential, e.g., neither to the first load terminal **11**, nor to the second load terminal **12**, nor to the control terminal **13**. In an embodiment, the electrically floating barrier region **105** is connected, by means of a connection having a high ohmic resistance, to a defined electrical potential (e.g., to an electrical potential of a contact or to an electrical potential of another semiconductor region). For example, by means of said high ohmic connection, during a switching operation, the electrical potential of the barrier region **105** is temporarily decoupled from the defined electrical potential. Said decoupling may occur on a time scale of said switching operation, e.g., for at least 10 ns, or at least 100 ns, or at least 10 μs. For example, the resistance of said high ohmic connection amounts to more than 1e2Ω, or to more than 1e6Ω.

In an embodiment, an ohmic resistance, e.g. measured during a standstill situation, between the first load terminal **11** and the barrier region **105** amounts to more than 1e2Ω, or to more than 1e6Ω.

For example, for ensuring that the barrier region **105** is electrically floating, the barrier region **105** does not extend into the transition region **1-5**; e.g., the barrier region **105** can exclusively be arranged within the active cell region **1-2**, as illustrated in FIG. **1**.

For example, the barrier region **105** does not extend into the transition region **1-5**. As has been explained above, the transition region **1-5** may be equipped with some of the IGBT cells **1-1** and hence be considered as an active region of the power semiconductor device **1**, i.e. a part of the power semiconductor device **1** that also conducts a part of the load current.

In an embodiment, the transition region **1-5** does neither include a section of the electrically floating barrier region **105** nor any further electrically floating semiconductor region of the second conductivity type. For example, there is no floating p-doped semiconductor region included in the transition region **1-5**.

The barrier region **105** is electrically floating, and, at the same time, the barrier region **105** can be arranged in contact with at least some of the trenches of the IGBT cells **1-1**, as has been explained above. Thus, the barrier region **105** may interface with the trench insulators **142**, **152** and **162**. For example, at least the source trench bottom **165** and/or at least the dummy trench bottom **155** extend into the barrier region **105**, e.g., such that the source trench electrode **161**, the dummy trench electrode **151** and the barrier region **105** have a common vertical extension range along the vertical direction Z of at least 100 nm, of at least 50 nm or of at least 1000 nm (wherein the barrier region **105** may extend further along the vertical direction Z as compared to the trench bottoms).

This aspect shall be elucidated in more detail with respect to FIGS. **6**A-C, which exemplarily and schematically illustrated a section of a vertical cross-section of the power to semiconductor device **1** in accordance with one or more embodiments, wherein FIG. **6**B shows a continuation from the section of FIG. **6**A along the first lateral direction X, and wherein FIG. **6**C shows a continuation from the section of FIG. **6**B along the first lateral direction X.

Starting at FIG. **6**A, the first load terminal **11** may be partially covered by an insulation structure **80**, e.g., an encapsulation. Within the active cell region **1-2**, there is arranged a plurality of said IGBT cells **1-1**, each of which exhibits said exemplary contacting scheme/neighborhood relationship, namely: "oDoSoSkGkSoSoD". In another embodiment, a different contacting scheme is employed.

The active mesas **18** are electrically connected to the first load terminal **11** by means of said first contact plugs **113**, and the source electrodes **161** of the source trenches **16** are electrically connected to the first load terminal **11** by means

of second contact plugs **115**. The control electrodes **141** of the control trenches **14** and the dummy electrodes **151** of the dummy trenches **15** are electrically connected to the control terminal **13**, e.g., by means of a gate runner **135** (cf. FIG. **6**B).

Within the transition region **1-5**, there is arranged one further IGBT cell **1-1** that may also exhibit the contacting scheme "oDoSoSkGkSoSoD" or a contacting scheme different therefrom. Further along the first lateral direction X, there is arranged one further dummy trench **15**, further source trenches **16** and one control trench **14**, adjacent to which there are arranged two active mesas **18**. Hence, within the transition region **1-5**, a part of the load current can be conducted.

The trench pattern may continue along the first lateral direction X also within the edge termination region **1-3**, wherein such trenches within the edge termination region **1-3** may be source trenches **16**. The mesas between said source trenches **16** may be electrically connected to the first load terminal **11** by means of the first contact plugs **113**. Hence, the arrangement of the source trenches **16** and the mesas in between these trenches that are electrically connected to the first load terminal **11** may form charge carrier drainage cells.

Within the edge termination region **1-3**, there can further be arranged a semiconductor well region **109** of the second conductivity type. For example, the well region **109** is p-doped and extends from the insulation layer **112** along the vertical direction Z, e.g., further as compared to the total extension of the trenches **14**, **15**, **16**, and **16**. For example, the well region **109** extends about as deep into the semiconductor body as the barrier region **105**.

Still referring to FIG. **6**A, the barrier region **105** may terminate at the transition between the active cell region **1-2** and the transition region **1-5**. For example, the barrier region **105** is exclusively arranged within the active cell region **1-2** and does neither extend into the transition region **1-5** nor into the edge termination region **1-3**.

On the other side, the well region **109** is exclusively arranged within the edge termination region **1-3** and does neither extend into the transition region **1-5** nor into the active cell region **1-2**. As has been elucidated above, the transition region **1-5** may entirely surround the active cell region **1-2** and may in turn be entirely surrounded by the edge termination region **1-3**. The minimum width W of the transition region **1-5**, i.e., the minimum distance between the barrier region **105** and the well region **109** amounts to 1 μm, wherein said minim width may be greater than 1 μm, e.g. greater than 3 μm, greater than 5 μm or even greater than 10 μm or than 20 μm. Along said width W, a portion of the drift region **100** may be present.

As the well region **109** is electrically connected to the first load terminal **11**, e.g., by means of said first contact plugs **113**, as exemplarily illustrated, the electrical potential within the well region **109** can be substantially identical to the electrical potential of the first load terminal **11**. Hence, by means of the transition region **1-5** and its minimum width W, it can be more reliably ensured that the barrier region **105** is indeed electrically floating.

In an embodiment, the well region **109** has an electrically activated maximal dopant concentration within the range of 1e15 to 5e18 cm^{-3}. It may extend along the vertical direction Z, e.g., further as the trenches **14**, **15**, **16**, e.g. down to a level substantially corresponding to the lower pn-junction **1052** formed between the barrier region **105** and the drift region **100**.

Now referring to FIG. **6**B, the well region **109** may extend along the first lateral direction X until it interfaces with a semiconductor VLD (variation of the lateral doping) or JTE (junction termination extension) region **107**. Also the VLD/JTE region **107** may be of the second conductivity type and may have a lower dopant concentration than the well region **109**. In general, the concept of such VLD or JTE region within a termination structure of a power semiconductor device is known to the skilled person and, therefore, it is refrained from explaining the function of the VLD or JTE region **107** in greater detail herein. For safety reasons, the VLD/JTE region **107** may be isolated from the electrical potential of the gate runner **135** by means of a thicker oxide layer **85**, which may be LOCOS layer or a recessed field oxide. Alternatively, other termination concepts known to the skilled person may be used.

For example, the gate runner **135** laterally overlaps with each of the well region **109** and the VLD region **107**.

Now referring to FIG. **6**C, the VLD region **107** may terminate at the position within the edge termination region **1-3** well before the chip edge **1-4**. The region between the chip edge **1-4** and the termination of the VLD region **107** may essentially be constituted by an unstructured section of the drift region **100**, wherein, in proximity to the chip edge **1-4**, a channel stopper arrangement can be provided. In general, the concept of a channel stopper arrangement in proximity to the chip edge of the power semiconductor device is also known to the skilled person. For example, in accordance with the embodiment exemplarily illustrated in FIGS. **6**A-C, for forming the channel stopper arrangement, there is provided a collector contact **121** that exhibits the electrical potential of the second load terminal **12**. Connected thereto is an electrode of a trench **125**. For example, trench **125** follows the course of the termination region **1-3** in that it also entirely surrounds the transition region **1-5**. Further trenches **1251** and **1252** may be provided for forming the channel stopper arrangement. The trenches **125**, **1251** and **1252** may be flanked by a semiconductor region **127** of the second conductivity type.

In an embodiment, the barrier region **105** has a lateral structure. For example, the barrier region **105** is formed as a laterally structured layer that extends throughout the entire active cell region **1-2**, e.g., until it interfaces with the transition region **1-5**. Hence, the barrier region **105** may be exclusively arranged within the active cell region **1-2** and does not extend into the transition region **1-5**. Within the active cell region **1-2**, the barrier region **105** can be laterally structured.

For example, the IGBT cells **1-1** are configured with a lateral structure according to a first layout having a first pitch, and wherein the lateral structure of the barrier region **105** is configured according to a second layout, the second layout having a second pitch at least twice as large as the first pitch. Hence, the lateral structure of the barrier region **105** can be coarser as compared to the trench pattern.

The lateral structure of the barrier region **105** can be formed by a plurality of pass-through passages **1053** (in the following also simply referred to as "passages"). Such concept is exemplarily illustrated in the general manner in FIG. **7**. For example, according the second layout, each of the pass-through passages **1053** may exhibit a maximum lateral extension at least twice as large as a minimum trench width and/or a minimum mesa width formed in accordance with the first layout.

In an embodiment, the one or more passages **1053** provide for a load current passage for currents below 10% or even below 1% of the nominal load current of the power semi-

conductor device **1**. For larger load currents, the whole active cell region **1-2**, irrespective of whether parts bilaterally overlap with the barrier region **105** or not, carry the load current. Thus, in accordance with an embodiment, for load currents below 10% or even below 1% of the nominal load current does not have to traverse the barrier region **105**, but may path through the one or more passages **1053**. For example, the barrier region **105** is absent, i.e., exhibits said passages **1053**, in a vertical projection (along the vertical direction Z) of the inversion channels that may be induced in the active mesas **18**, e.g., in a vertical projection of the source regions **101**.

The possible effect described in the preceding paragraph has also been elucidated in greater detail above, namely with respect to the first share of the total volume of the active mesas **18** that does not laterally overlap with the barrier region **105** and the second share of the total volume of the active mesas **18** that does laterally overlap with the barrier region **105**.

In an embodiment, the one or more passages **1053** are positioned and/or dimensioned so as to laterally overlap with at least a subset of the source regions **101**.

For example, the barrier region **105** may form a "carpet" arranged within the active cell field **1-2** and, e.g., substantially in parallel to each of the first load terminal **11** and the second load terminal **12** and separated from each of these terminals **11**, **12** by means of at least the drift region **100**. Such carpet like configuration of the barrier region **105** may be positioned within the semiconductor body **10** such that the trench bottoms **145** and **155** and/or **165** may plunge into the barrier region **105**.

The passages **1053** may laterally overlap with one or more of the active mesas **18**. Adhering to the visual vocabulary introduced above, the barrier region **105** may hence be implemented as a "patchwork carpet", wherein the one or more passages **1053** can be entirely filled with sections of the drift region **100**. The dimensions, the positions and the numbers of passages **1053** can, for example, be chosen in accordance with the cell configuration.

The barrier region **105** may be implemented as a contiguous barrier layer within the active cell field **1-2** of the power semiconductor device **1**, e.g., as said "carpet". As has been indicated above, each of the dummy trench bottoms **155** and/or the control trench bottoms **145** and or the source trench bottoms **165** may extend into the barrier region **105**, e.g., the dummy trench **15** and/or the control trench **14** and/or the source trench **16** may extend into the barrier region **105** by at least 100 nm, by at least 500 nm or by at least 1000 nm.

Still referring to FIG. **7**, for example, in accordance with variant A, the passages can have a stripe configuration arranged substantially perpendicular to the stripe configuration of the IGBT cells **1-1**. In another embodiment, a central pass-through passage **1053** of large extensions is provided (variant B). In accordance with variants B and D, a plurality of smaller the passages **1053** is provided, which can be distributed according to various patterns.

Each of the plurality of passages **1053** can be filled by a section of the drift region **100**. Thus, within the passages **1053**, an n-doped semiconductor region may be present which exhibits a dopant concentration corresponding to the dopant concentration of the drift region. In another embodiment, which will be elucidated in more detail further below, some or all of the passages **1053** can also be filled by means of (deeper) trenches.

Some embodiments are provided with a barrier region **105** whose pass-through passages **1053** are positioned and dimensioned according to a predefined design rule. For example, said second layout can be configured in accordance with the design rule. The positions and dimensions of the passages **1053** may have significant influence on the dynamic behavior of the power semiconductor device **1**, e.g., regarding a voltage slope (dV/dt) during a turn-on operation.

For example, in accordance with a first provision of such design rule, a distance between two arbitrary ones of the pass-through passages **1053** that are arranged adjacent to each other is smaller than 1 mm.

A second provision of such design rule can be that the barrier region **105** is arranged within a semiconductor layer of the semiconductor body **10**, the semiconductor layer extending entirely and exclusively within the active cell region **1-2** and exhibiting a total volume, wherein the pass-through passages **1053** form at least 1% and at most 50% of said total volume. The remaining volume of the semiconductor layer, i.e., the p-doped part of the barrier region **105**, can be formed by semiconductor regions of the second conductivity type. As already indicated above, i.e., the remaining volume, can have a dopant concentration (cf. concentration CC in FIG. **5**) greater than 1e14 cm^{-3} and smaller than 4e17 cm^{-3}, said dopant concentration being present within an extension along the vertical direction Z of at least 0.1 μm or at least 0.5 μm.

A third provision of such design rule can be, that the barrier region **105**, despite its passages **1053**, connects the inactive mesas **19** included in the plurality of IGBT cells **1-1** of the active cell region **1-2** with each other.

A fourth provision of such design rule can be that the passages **1053** laterally overlap with at least a subset of the active mesas **18** of the active cell region **1-2**. For example, the one or more passages **1053** are positioned and/or dimensioned so as to laterally overlap with at least a subset of the source regions **101**.

The fifth provision of such design rule can be that the passages **1053** laterally overlap with at least a subset of the control trenches **14** of the active cell region **1-2**.

A further provision of such design rule can be that the barrier region **105** extends at least partially into subset of the active mesas **18**, e.g., without establishing contact with the respective control trench **14** that is laterally flanked by the respective active mesa **18**. For example, thereby, the barrier region **105** can be configured to provide for an electrically conductive path between a section of a respective one of the subset of the active mesas **18** and the bottoms **155** of the dummy trenches **15**. Hence, it can be provision of the design rule that the pass-through passages **1053** laterally overlap with one or more of the active mesas **18** of the IGBT cells **1-1**. For example, the design rule can specify that the pass-through passages **1053** laterally overlap, with respect to the total number of active mesas **18** present within the active cell region **1-2**, with at least 1% and at most 50% of the active mesas **18**. As explained above, the lateral overlap between the barrier region **105** and a respective one of the active mesas **18** may occur partially; i.e., the barrier region **105** must not necessarily entirely overlap with the respective active mesa **18**, but, e.g., up to 10%, up to 30% or up to 70% of the mesa width of the respective active mesa **18**.

With respect to FIGS. **8**A-D, which each schematically and exemplarily illustrate a section of a horizontal projection of a power semiconductor device **1** in accordance with some embodiments, exemplary lateral structures of the barrier region **105** shall be presented.

Referring to each of FIGS. **8**A-D, the barrier region **105** may extend entirely and exclusively within the active cell

region **1-2**. Within the active cell region **1-2**, said plurality of IGBT cells **1-1** may be provided, each of which comprises at least one of said control trenches **14** that may be laterally flanked, on each side, by a respective active mesa **18**, each of which comprises the source region **101** that is electrically connected to the first load terminal **11**. The IGBT cells **1-1** that are included in the active region **1-2** may exhibit a configuration as has been explained with respect to FIGS. **6**A-C. The IGBT cells **1-1** exhibit a stripe configuration substantially orientated along the second lateral direction Y, as has also been explained above. For example, each IGBT cell **1-1** extends along the second lateral direction throughout the entire active cell region **1-2**.

In FIGS. **8**A-D, a plurality of source regions **101** is illustrated, wherein only some are provided with a respective reference sign. For example, each of the illustrated source regions **101** forms a part of two active mesas **18**, in between which there is arranged a respective control trench **14**, as illustrated in FIG. **6**A.

The active cell region **1-2** can be entirely surrounded by the transition region **1-5**, which in turn can be entirely surrounded by the edge termination region **1-3**. The transition region **1-5** and the edge termination region **1-3** may be configured in a manner as has exemplarily been explained with respect to FIGS. **6**A-C.

As illustrated in FIGS. **8**A-D, the lateral structure of the barrier region **105**, which is formed or, respectively defined by the number, dimensions and positions of the passages **1053**, can exhibit a significantly greater pitch as compared to the pitch according to which the layout of the trench pattern is formed.

For example, referring to FIG. **8**A, the passages **1053** may exhibit an orientation substantially in parallel to the orientation of the stripe configuration of the IGBT cells **1-1**. A respective one of the passages **1053** may laterally overlap with a plurality of adjacent trenches and mesas. It has been pointed out above that it may be appropriate to position the passages **1053** such that they laterally overlap with at least a subset of the active mesas **18**, which is the case in accordance with the embodiment illustrated in FIG. **8**A; there, the position of the passages **1053** is chosen such that the passages **1053** overlap with a subset of the source regions **101**. Hence, a load current of said subset of active mesas **18** does not traverse the barrier region **105**, but flows through its passages **1053**. As further illustrated in FIG. **8**A, in accordance with an embodiment, also the passages **1053** may terminate at the transition between the active cell region **1-2** and the transition region **1-5**.

The embodiment illustrated in FIG. **8**B essentially corresponds to the embodiment illustrated in FIG. **8**A, wherein the passages **1053** are dimensioned and positioned so as to be entirely integrated within the barrier region **105** and so as to not intersect with the transition region **1-5**.

In accordance with the embodiment schematically and exemplarily illustrated in FIG. **8**C, the passages **1053** exhibit an orientation substantially perpendicular to the orientation of the stripe configuration of the IGBT cells **1-1**. Such orientation, which is also schematically and exemplarily illustrated in the perspective projection of FIG. **9**, may support dampening or, respectively, avoiding of a voltage swing during the switching operation of the power semiconductor device **1**. The embodiment illustrated in FIG. **8**D essentially corresponds to the embodiment illustrated in FIG. **8**C, wherein the passages **1053** are dimensioned and positioned so as to be entirely integrated within the barrier region **105** and so as to not intersect with the transition region **1-5**.

Now referring to the embodiments that are schematically and exemplarily illustrated in FIGS. **10** and **11**, some or all of the passages **1053** may also be filled, in addition or in alternative to the drift region **100**, with lower sections of trenches of the IGBT cells **1-1**. For example, some or all of the passages **1053** are filled with lower sections of the control trenches **14**. In accordance with the embodiment illustrated in FIG. **10**, this may be achieved by designing the control trenches **14** was a greater total extension along the vertical direction Z as compared to the trenches that do not fill the passages **1053**. In accordance with the embodiment illustrated in FIG. **11**, this may be achieved by providing the barrier region **105** such that the passages **1053** are arranged within respective local elevations (with respect to the vertical direction Z). Further below, exemplary methods of producing structures as illustrated in FIGS. **10** and **11** will be presented.

As further illustrated in FIGS. **10** and **11**, in an embodiment, the contacting scheme is different from the above-mentioned exemplary contacting scheme, for example, the contacting scheme of each IGBT cell **1-1** within the active cell region **1-2** is "oSkGkSoDoD", but also in accordance with this contacting scheme, the active mesas **18** are laterally confined by a respective source trench **16**.

Now referring to FIGS. **12** to **19**, further exemplary lateral structures of the barrier region **105** shall be presented. In accordance with each of the embodiments schematically and exemplarily illustrated in FIGS. **12** to **19**, the contacting scheme for each IGBT cell **1-1** within the active region **1-2** is "oDoSoSkGkSoSoD". However, as noted above, in other embodiment, a different contacting scheme is employed, examples of which have been presented further above.

For example, referring to FIG. **12**, the passages **1053** extend in parallel to the stripe configuration of the control trench **14**. The barrier region **105** partially extends into some of the active mesas **18** that are arranged adjacent to each side of the respective control trench **14**. As illustrated, the passages **1053** may occur, along the first lateral direction X, at every fifth IGBT cell **1-1**. Hence, a distance D between two neighbored passages **1053** along the first lateral direction X may be greater than 500 μm, e.g., amount to approximately 700 μm. For example, the barrier region **105** hence entirely laterally overlaps with at least always exactly 80% of the total number of IGBT cells **1-1** within the active region **1-2**. The remaining 20% of the total number of IGBT cells **1-1** within the active region **1-2** may laterally overlap with the passages **1053**, e.g., by means of their respective control trench **14** and their respective active mesas **18**, as illustrated in FIG. **12**. Further, as also illustrated in FIG. **12**, the well region **109** does not extend into the transition **1-5**, and the barrier region **105** does also not extend into the transition region **1-5**. Rather, the transition region **1-5** separates the barrier region **105** from the well region **109**.

In accordance with the embodiment shown in FIG. **13**, the passages **1053** may also each be provided with a smaller rectangular cross-section and positioned in accordance with an island pattern within the active cell region **1-2**. Each of the passages **1053** may have a width along the first lateral direction X within the range of 5 μm to 20 μm and the length along the second lateral direction Y within the range of 5 μm to 20 μm.

In an embodiment, for each of the passages **1053**, the width along the first lateral direction X is greater than the length along the second lateral direction Y of the respective passages **1053**, e.g., the width-to-length ratio of each passage is greater than 2, or even greater than 3. Hence, the passages may have geometric configuration so as to extend

rather perpendicular to the stripe configuration of the IGBT cells **1-1** and not in parallel thereto. Such configuration may be beneficial for avoiding/reducing an undesired voltage swing/oscillation on the control electrodes **141**.

Along the first lateral direction X, each IGBT cell **1-1** (of which, in FIG. **13**, only the source regions **101** and the control trenches **14** are illustrated, wherein each of the illustrated source regions **101** is electrically connected to two respective active mesas **18** that are separated from each other by means of a respective control trench **14**) may laterally overlap with one of the passages **1053**. Along the second lateral direction Y, each IGBT cell **1-1** may laterally overlap with a plurality of the passages **1053**. For example, a distance Dx between two passages **1053** that are neighbored along the first lateral direction X is within the range of some micrometers, e.g., 3 μm to 5 μm. Further, a distance Dy between two passages **1053** that are neighbored along the second lateral direction Y can be within the range of some micrometers, e.g., 5 μm to 20 μm, e.g. approximately 15 μm.

Along the second lateral direction Y, the source regions **101** can be positioned with a distance Ds within the range of 0.1 μm to 20 μm. For example, each passage **1053** laterally overlaps with at least three of the source regions **101** along the second lateral direction Y.

A similar configuration is schematically and exemplarily illustrated in FIG. **14**. Along the first lateral direction X, each IGBT cell **1-1** may laterally overlap with one of the passages **1053**. Along the second lateral direction Y, each IGBT cell **1-1** may laterally overlap with a plurality of the passages **1053**, wherein the distance Dy along the second lateral direction is increased as compared to the embodiment shown in FIG. **13**.

For example, the passages **1053** do not laterally overlap with the dummy trenches **15**. Rather, each of the dummy trenches **15** extends into the barrier region **105**. For example, the passages **1053** overlap partially with the control trenches **14** and the source trenches **16**.

The lateral structure of the barrier region **105** schematically and exemplarily illustrated in FIG. **15** essentially corresponds to the structure as illustrated in each of FIGS. **13** and **14**. Accordingly, along the first lateral direction X, each IGBT cell **1-1** may laterally overlap with one of the passages **1053**. Along the second lateral direction Y, each IGBT cell **1-1** may laterally overlap with a plurality of the passages **1053**, wherein the distance Dy along the second lateral direction is increased as compared to the embodiment shown in FIG. **14**. E.g., the distance Dy between two passages **1053** that are neighbored along the second lateral direction amounts is within the range of several micrometers, e.g., 1 μm to 2000 μm.

In accordance with variant schematically and exemplarily illustrated in FIG. **16**, the lateral structure of the barrier region **105** has a chessboard like pattern. According to the embodiment, about 50% of the total volume of the barrier region **105** is constituted by the passages **1053** (e.g., filled with respective sections of the drift region **100**) and the remaining 50% of the barrier region **105** are p-doped regions. For example, each passage **1053** may exhibit a rectangular cross-section. Each of the passages **1053** may have a width along the first lateral direction X so as to overlap with three neighbored IGBT cells **1-1**, and a length along the second lateral direction Y so as to overlap with three neighbored source regions **101**. Along the second lateral direction Y, the source regions **101** can be positioned within a distance Ds within the range given above. As illustrated, in accordance with the embodiment of FIG. **16** and in contrast to the embodiment shown in FIG. **14**, the passages **1053** may laterally overlap with the dummy trenches **15**.

In accordance with the further variant that is schematically and exemplarily illustrated in FIG. **17**, compared to the lateral structure shown in FIG. **16**, the volume share of the passages **1053** may be decreased from 50% to less than 20%. Each of the passages **1053** may have a width along the first lateral direction X so as to overlap with three neighbored IGBT cells **1-1**, and a length along the second lateral direction Y so as to overlap with three neighbored source regions **101**. Along the second lateral direction Y, the source regions **101** can be positioned within a distance Ds within the range given above. Again, as illustrated, also in accordance with the embodiment of FIG. **17** and in contrast to the embodiment shown in FIG. **14**, the passages **1053** may laterally overlap with the dummy trenches **15**. Further, the distance the distance Dx along the first lateral direction X between two neighbored passages **1053** may amount to the total width of three neighbored IGBT cells **1-1**. The distance Dy along the second lateral direction Y may be greater than the distance Dx. For example, the distance Dy along the second lateral direction Y between two neighbored passages may amount to at least eight times the distance Ds.

While keeping the dimensions of the passages **1053** unmodified with respect to the embodiment shown in FIG. **17**, in accordance with the embodiment schematically and exemplarily illustrated in FIG. **18**, the density of the passages **1053** may be increased and, hence, the distances Dx and Dy decreased. As further illustrated in FIGS. **17** and **18**, the passages **1053** may be positioned such that two passages **1053** that are neighbored, at distance Dy, along the second lateral direction Y do not exhibit a lateral overlap along the first lateral direction X (as illustrated in FIG. **17**) or such that two passages **1053** that are neighbored, at distance Dx, along the first lateral direction X do not exhibit a lateral overlap along the second lateral direction Y (as illustrated in FIG. **18**).

While keeping the dimensions of the passages **1053** unmodified with respect to the embodiment shown in FIG. **17**, in accordance with the embodiment schematically and exemplarily illustrated in FIG. **19**, the density of the passages **1053** may be decreased and, hence, the distances Dx and Dy increased.

Further variations of the lateral structure of the barrier region **105** are possible. For example, each variation of the lateral structure of the barrier region **105**, e.g., as they are exemplarily and schematically illustrated in FIGS. **7** to **19**, obeys one or more of the following provisions of a design rule:

(i) a distance, e.g., said distances Dx and Dy, between two arbitrary ones of the pass-through passages **1053** that are arranged adjacent to each other is smaller than 1 mm;

(ii) the barrier region **105** is arranged within said semiconductor layer of the semiconductor body **10**, the semiconductor layer extending entirely and exclusively within the active cell region **1-2** and exhibiting a total volume, wherein the pass-through passages **1053** form at least 1% and at most 50% of said total volume. The remaining volume of the semiconductor layer, i.e., the p-doped part of the barrier region **105**, is formed by semiconductor regions of the second conductivity type;

(iii) the barrier region **105**, despite its passages **1053**, connects the inactive mesas **19** included in the plurality of IGBT cells **1-1** of the active cell region **1-2** with each other;

(iv) the passages **1053** laterally overlap with at least a subset of the active mesas **18** of the active cell region **1-2** (For example, the one or more passages **1053** are positioned and/or dimensioned so as to laterally overlap with at least a subset of the source regions **101**);

(v) the passages **1053** laterally overlap with at least a subset of the control trenches **14** of the active cell region **1-2**;

(vi) the barrier region **105** extends entirely and exclusively within the active cell region **1-2** (and not into the transition region **1-5**)

(vii) the barrier region **105** extends at least partially into subset of the active mesas **18** (e.g., without establishing contact with the respective control trench **14** that is laterally flanked by the respective active mesa **18**). For example, thereby, the barrier region **105** can be configured to provide for an electrically conductive path between a section of a respective one of the subset of the active mesas **18** and the bottoms **155** of the dummy trenches **15**.

(viii) the lateral structure of the barrier region **105** is configured according to the second layout that has the second pitch which is at least twice as large as the first pitch (the IGBT cells **1-1** are configured with a lateral structure according to the first layout having the first pitch, as indicated above).

(ix) if present (e.g., when the power semiconductor device **1** is configured as an RC-IGBT), the passages **1053** may laterally overlap with n-type emitters electrically connected to the second load terminal **12**

As has been explained above, the position and/or the lateral structure of the barrier region **105** (e.g., formed by one or more passages as illustrated in FIGS. **7-19**) may allow diving the total volume of the active mesas **18** into the first share and into the second share, the first share not laterally overlapping with the barrier region **105** and the second share laterally overlapping with the barrier region **105**. As explained above, the first share of the active mesas **18** laterally overlaps with the at least one passage **1053** of the barrier region **105** or with another section of the drift region **100** where the barrier region **105** is not present (e.g., within the transition region **1-5**). In contrast, the second share of the active mesas **18** laterally overlaps with the barrier region **105**. For example, the load current conducted by the second share traverses the barrier region **105**. As has further been explained above, in an embodiment, the first share is configured to carry the load current at least within the range of 0% to 100% of the nominal load current for which the power semiconductor device is designed. The second share may be configured to carry the load current only if it exceeds at least 0.5% of the nominal load current. Hence, the first share of active mesas **18** can be considered as an "ignition volume" which, e.g., during turn-on of the power semiconductor device **1** starts to conduct the load current whereas the second share initially remains inactive. Then, if the load current exceeds the threshold of at least 0.5% of the nominal load current (wherein this threshold can be higher than 0.5%, e.g., higher than 1%, e.g., at least 5% or at least 10%), the barrier region **105** may become more conductive such that the second share may also carry the load current.

Herein presented is also a method of processing a power semiconductor device. A flow chart of an exemplary method **2** is schematically illustrated in FIG. **20**. For example, in the first step **2100**, a semiconductor body is provided.

The method **2** can be implemented so as to provide a power semiconductor device that comprises an active cell region with a drift region of the first conductivity type; a plurality of IGBT cells at least partially arranged within the active cell region, wherein each of the IGBT cells comprises at least one trench that extends into the drift region along a vertical direction; an edge termination region surrounding the active cell region; and a transition region arranged between the active cell region and the edge termination region, the transition region having a width along a lateral direction from the active cell region towards the edge termination region, wherein at least some of the IGBT cells are arranged within, or, respectively, extend into the transition region.

For example, method **2** may further comprise step **2200**, during which an electrically floating barrier region of the second conductivity type is provided, wherein the electrically floating barrier region is arranged within the active cell region and in contact with at least some of the trenches of the IGBT cells, and wherein the electrically floating barrier region does not extend into the transition region.

According to another embodiment, method **2** is implemented so as to provide a power semiconductor device that comprises a first load terminal and a second load terminal, the power semiconductor device being configured to conduct a load current along the vertical direction between said terminals and comprising: an active cell region with a drift region of the first conductivity type; an edge termination region having a well region of the second conductivity type; a plurality of IGBT cells arranged within the active cell region, wherein each of the IGBT cells comprises a plurality of trenches that extend into the drift region along the vertical direction and that laterally confine a plurality of mesas. The plurality of trenches include: at least one control trench having a control electrode; at least one dummy trench having a dummy electrode electrically coupled to the control trench; at least one source trench having a source electrode electrically connected with the first load terminal. The plurality of mesas include at least one active mesa arranged between the at least one control trench and the at least one source trench; and at least one inactive mesa arranged adjacent to the at least one dummy trench. Step **2200** may be carried out so as by providing an electrically floating barrier region of the second conductivity type, wherein at least both a bottom of the dummy trench and a bottom of the source trench extend at least partially into the electrically floating barrier region, and wherein a portion of the drift region located in a lateral direction between the electrically floating barrier region and the well region has a lateral extension of at least 1 μm in said lateral direction.

For example, regarding both embodiments of method **2** described above, the barrier region can be formed before forming the trenches of the IGBT cells. In another embodiment, the barrier region is formed after the trenches of the IGBT cells have been formed. In a yet further embodiment, the barrier region is formed during formation of the IGBT cells, e.g. after the trenches have been etched and before the trenches are filled with trench electrodes.

Exemplary embodiments of the method **2** can correspond to the exemplary embodiments of the power semiconductor device **1** explained above. In particular, method **2** can be carried out so as to form the barrier region with a lateral structure, examples of which have been presented above, e.g., with respect to FIGS. **7** to **19**.

In an embodiment of method **2**, the lateral structure of the barrier region **105** is formed by creating a homogenously doped p-layer and by locally providing an n-type counter-doping so as to form the passages **1053**.

In another embodiment of method **2**, the lateral structure of the barrier region **105** is formed by creating a homog-

enously doped p-layer and pinching through the layer by means of trench depth variation (cf. FIG. **10**), e.g., at least partially to a depth beyond the maximum dopant concentration (cf. CCM in FIG. **5**).

In yet another embodiment that the lateral structure of the barrier region **105** is formed by using a mask arrangement.

For example, the barrier region **105** is fabricated by means of a deep implantation, e.g., after the formation of the trenches by means of providing the trench insulators **142**, **152**, **162**, **172** and the polysilicon filling for forming the trench electrodes **141**, **151**, **161**, **171**. Then, achievement of the projected range (e.g. 5 μm, depending on the trench depth, as explained above) of the barrier region **105** could require high implantation energies, e.g., in the range of 4 MeV, e.g., in case of boron as the implantation material. For example, masking of the implantation can be simplified by the presence of a flat surface, following the polysilicon filling of the trenches. The implantation can occur at high energy, but the dose can be low. Therefore, the trench insulators **142**, **152**, **162**, **172** are not damaged.

In an alternative embodiment, the barrier region **105** is created before the trench fabrication process. For example, this can be carried out by implementing a local shallow p-type implantation followed by an epitaxial growth with a target thickness substantially equal to the trench depth. In this case, slowly diffusing p-type species can be employed as implantation material. For example, such variant can be employed for forming the embodiment in accordance with FIG. **10**. The deeper control trenches **14** can be formed, e.g., by tuning the trench layout width and/or by providing separate trench etch blocks for shallow and deeper trenches. Then, the deeper control trenches **14** extend along the vertical direction Z beyond the barrier region **105** and enter the drift region **100**, namely its lower section **100-2**, as illustrated in FIG. **10**. With regards to the embodiment illustrated in FIG. **11**, the local elevations of the barrier region **105** can be achieved, e.g., by means of locally providing a counter-doping, e.g., by locally carrying out an n-type implantation. Alternatively, only the p-type implantation is carried out, wherein, implantation dampening elements may be provided at selected positions on the surface of the semiconductor body **10**, e.g., at positions where one or more of the designated control trenches **14** are to be formed. Due to the dampening elements, the penetration depth of the implantation ions is decreased, thereby causing the local elevations in the barrier region **105** in the outcome. Then, all trenches **14**, **15**, **16**, **17** may exhibit the same depth, while those which laterally overlap with the local elevations of the barrier region **105** may extend along the vertical direction Z beyond the barrier region **105** and enter the drift region **100**, namely its lower section **100-2**, as illustrated in FIG. **11**. Thereby, the pass-through passages **1053** can be formed, in accordance with an embodiment. For example, the dampening elements are formed by generating local steps on the semiconductor body surface (e.g., by plasma etching or sacrificial recessed LOCOS), wherein this can be followed by a p-type implantation and silicon epitaxial regrowth of proper thickness, so that the trenches will align properly to the p-type implantation profile.

In accordance with one or more embodiments described herein, an IGBT having a plurality of IGBT cells configured in accordance with an MPT structure is presented, wherein each IGBT cell has a control trench for controlling the load current in at least one active mesa and at least one dummy trench with a trench electrode also electrically connected to the control terminal and arranged adjacent to the at least one inactive mesa, wherein the active mesa and the bottom of the dummy trench are connected to each other by means of a laterally structured and electrically floating p-doped barrier region. Due to such connection, during the switching operation of the IGBT, a voltage swing on the control terminal may be reduced, in accordance with an embodiment. This may allow for an improved control of dV/dt by means of a gate signal, e.g., during switching of the IGBT. Furthermore, in an embodiment, the lateral structure of the p-barrier region may avoid a snapback in the transfer and output characteristics of the IGBT. For example, at currents below 10% or even below 1% of nominal load current, the load current is carried by the active mesas not covered by the p-barrier region (e.g., where there is barrier passage). For larger currents, an upper pn-junction formed by a transition between the barrier region and the drift region above the barrier region forward bias mode with respect to the electron current and all active mesas within the active cell region, irrespective of whether they are covered by a p-barrier region or not, carry the load current.

In the above, embodiments pertaining to power semiconductor devices and corresponding processing methods were explained. For example, these power semiconductor device are based on silicon (Si). Accordingly, a monocrystalline semiconductor region or layer, e.g., the semiconductor body **10** and its regions/zones **100**, **101**, **102**, **105**, **107**, **108**, **109** can be a monocrystalline Si-region or Si-layer. In other embodiments, polycrystalline or amorphous silicon may be employed.

It should, however, be understood that the semiconductor body **10** and its doped regions/zones can be made of any semiconductor material suitable for manufacturing a semiconductor device. Examples of such materials include, without being limited thereto, elementary semiconductor materials such as silicon (Si) or germanium (Ge), group IV compound semiconductor materials such as silicon carbide (SiC) or silicon germanium (SiGe), binary, ternary or quaternary III-V semiconductor materials such as gallium nitride (GaN), gallium arsenide (GaAs), gallium phosphide (GaP), indium phosphide (InP), indium gallium phosphide (InGaPa), aluminum gallium nitride (AlGaN), aluminum indium nitride (AlInN), indium gallium nitride (InGaN), aluminum gallium indium nitride (AlGalnN) or indium gallium arsenide phosphide (InGaAsP), and binary or ternary II-VI semiconductor materials such as cadmium telluride (CdTe) and mercury cadmium telluride (HgCdTe) to name few. The aforementioned semiconductor materials are also referred to as "homojunction semiconductor materials". When combining two different semiconductor materials a heterojunction semiconductor material is formed. Examples of heterojunction semiconductor materials include, without being limited thereto, aluminum gallium nitride (AlGaN)-aluminum gallium indium nitride (AlGalnN), indium gallium nitride (InGaN)-aluminum gallium indium nitride (AlGalnN), indium gallium nitride (InGaN)-gallium nitride (GaN), aluminum gallium nitride (AlGaN)-gallium nitride (GaN), indium gallium nitride (InGaN)-aluminum gallium nitride (AlGaN), silicon-silicon carbide (SixC1-x) and silicon-SiGe heterojunction semiconductor materials. For power semiconductor device applications currently mainly Si, SiC, GaAs and GaN materials are used.

Spatially relative terms such as "under", "below", "lower", "over", "upper" and the like, are used for ease of description to explain the positioning of one element relative to a second element. These terms are intended to encompass different orientations of the respective device in addition to different orientations than those depicted in the figures. Further, terms such as "first", "second", and the like, are also

used to describe various elements, regions, sections, etc. and are also not intended to be limiting. Like terms refer to like elements throughout the description.

As used herein, the terms "having", "containing", "including", "comprising", "exhibiting" and the like are open ended terms that indicate the presence of stated elements or features, but do not preclude additional elements or features.

With the above range of variations and applications in mind, it should be understood that the present invention is not limited by the foregoing description, nor is it limited by the accompanying drawings. Instead, the present invention is limited only by the following claims and their legal equivalents.

What is claimed is:

1. A power semiconductor device, comprising: an active cell region with a drift region of a first conductivity type and a channel region of a second conductivity type; a plurality of IGBT cells at least partially arranged within the active cell region, wherein each of the IGBT cells comprises at least one trench that extends into the drift region along a vertical direction; an edge termination region surrounding the active cell region; a transition region arranged between the active cell region and the edge termination region, the transition region having a width along a lateral direction from the active cell region towards the edge termination region, wherein at least some of the IGBT cells are arranged within, or, respectively, extend into the transition region; a barrier region of a second conductivity type, wherein the barrier region is arranged within the active cell region and in contact with a trench bottom of at least some of the trenches of the IGBT cells, wherein the barrier region does not extend into the transition region, and wherein a top surface of the barrier region is arranged below a bottom surface of the channel region along a vertical direction z; and a first load terminal and a second load terminal, the power semiconductor device being configured to conduct a load current along a vertical direction between the first and second load terminals, and wherein each IGBT cell has a micro-pattern-trench structure, wherein the barrier region is vertically separated from the channel region by at least a part of the drift region.

2. The power semiconductor device of claim **1**, wherein the barrier region forms each of an upper pn-junction with the drift region and a lower pn-junction with the drift region, the lower pn-junction being arranged lower than bottoms of each of the trenches from the plurality of IGBT cells.

3. The power semiconductor device of claim **1**, wherein each IGBT cell comprises:

at least one control trench having a control electrode;

at least one dummy trench having a dummy electrode;

at least one active mesa arranged adjacent to the at least one control trench, wherein the control electrode is configured to receive a control signal from a control terminal of the power semiconductor device and to control a load current in the active mesa; and

at least one inactive mesa arranged adjacent to the at least one dummy trench, wherein a transition between the first load terminal and the inactive mesa provides an electrical insulation at least for charge carriers of the first conductivity type.

4. The power semiconductor device of claim **3**, wherein the upper pn-junction is arranged within the at least one active mesa.

5. The power semiconductor device of claim **3**, wherein the upper pn-junction is arranged within the at least one inactive mesa, and wherein a transition between the first load terminal and the inactive mesa provides an electrical insulation at least for charge carriers of the first conductivity type.

6. The power semiconductor device of claim **3**, wherein the at least one active mesa comprises a local barrier region of the first conductivity type that is arranged above the barrier region and below the channel region of the at least one active mesa, the channel region having the second conductivity type.

7. The power semiconductor device of claim **6**, wherein a maximum dopant concentration of the local barrier region is at least twice as great as a maximum dopant concentration of the drift region.

8. The power semiconductor device of claim **6**, wherein:

each IGBT cell further comprises at least one source trench having a source trench electrode, the source trench electrode being electrically connected to the first load terminal, the at least one source trench being arranged between the control trench and the dummy trench, or the active mesa being laterally confined by the control trench and the source trench, or the inactive mesa being laterally confined by the source trench and the dummy trench; and

each IGBT cell further comprising at least one floating trench having a trench electrode, the trench electrode of the floating trench being electrically floating, the at least one floating trench being arranged between the control trench and the dummy trench, or the at least one source trench and the at least one floating trench being arranged between the control trench and the dummy trench; and

in a vertical cross-section of each IGBT cell, the respective IGBT cell is configured to prevent the load current from crossing the transition between the inactive mesa and the first load terminal; and

each active mesa includes a source region of the first conductivity type that is electrically connected to the first load terminal and has the channel region of a second conductivity type that separates the source region and the drift region, wherein, in the active mesa, at least a respective section of each of the source region, the channel region and the drift region are arranged adjacent to a sidewall of the control trench.

9. The power semiconductor device of claim **8**, wherein the control electrode and the dummy electrode are each electrically coupled to the control terminal.

10. The power semiconductor device of claim **8**, wherein the barrier region is configured to provide for an electrically conductive path between a section of the active mesa and a bottom of the dummy trench.

11. The power semiconductor device of claim **8**, wherein the barrier region connects the inactive mesas included in the plurality of IGBT cells of the active cell region with each other.

12. The power semiconductor device of claim **11**, wherein the barrier region has a maximum dopant concentration in a region where the bottom of the dummy trench extends into the barrier region.

13. The power semiconductor device of claim **1**, wherein a section of the drift region contacts the bottom surface of the channel region and extends along the vertical direction z to contact the top surface of the barrier region.

14. The power semiconductor device of claim **1**, wherein the transition region surrounds the active cell region.

15. The power semiconductor device of claim **1**, wherein the barrier region is electrically floating.

16. The power semiconductor device of claim **1**, further comprising a floating trench having an electrically floating trench electrode.

17. The power semiconductor device of claim **1**, wherein the barrier region is confined, along the vertical direction Z, by an upper section of the drift region **100** on one side and by a lower section of the drift region **100** on another side.

18. The power semiconductor device of claim **2**, wherein the upper pn-junction is arranged higher than the trench bottom of at least some of the trenches of the IGBT cells along the vertical direction z.

19. A power semiconductor device, comprising: an active cell region with a drift region of a first conductivity type and a channel region of a second conductivity type; a plurality of IGBT cells at least partially arranged within the active cell region, wherein each of the IGBT cells comprises at least one trench that extends into the drift region along a vertical direction; an edge termination region surrounding the active cell region; a transition region arranged between the active cell region and the edge termination region, the transition region having a width along a lateral direction from the active cell region towards the edge termination region, wherein at least some of the IGBT cells are arranged within, or, respectively, extend into the transition region; a barrier region of a second conductivity type, wherein the barrier region is arranged within the active cell region and in contact with a trench bottom of at least some of the trenches of the IGBT cells, wherein the barrier region does not extend into the transition region, wherein a top surface of the barrier region is arranged below a bottom surface of the channel region along a vertical direction z, and wherein the top surface of barrier region forms an upper pn-junction with the drift region; and a first load terminal and a second load terminal, the power semiconductor device being configured to conduct a load current along a vertical direction between the first and second load terminals, and wherein each IGBT cell has a micro-pattern-trench structure, wherein the barrier region is vertically separated from the channel region by at least a part of the drift region.

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